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AGRICULTURAL RESEARCH SERVICE PRECIPITATION FACILITIES AND RELATED STUDIES

David M. Hershfield

June 1971 ARS 41-176

Soil and Water Conservation Research Division
Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

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11	Pennsylvania Agricultural Experiment Station.
12, 13	South Dakota Agricultural Experiment Station.
14, 15	Texas Agricultural Experiment Station and Texas A&M University.
16	Vermont Agricultural Experiment Station.

FOREWORD

This collection of current precipitation studies by the Soil and Water Conservation Research Division, Agricultural Research Service, has been assembled both to provide an awareness of the location and scope of such studies and as a reference to some of the findings to date.

The studies are primarily aimed at providing information about precipitation pertinent to research on the hydrology of specific agricultural watersheds rather than for investigations of precipitation patterns for their own sake. Nevertheless, some of the gages in the observational program have been placed on an equally spaced grid or otherwise stratified so that information about the temporal and spatial variations of precipitation on the areas sampled are provided within practical limits. Although obtained primarily from rural areas, the findings from the networks can also be taken as indicative of precipitation in urban settings, except for large metropolitan areas where local conditions may cause unique patterns.

The distribution of precipitation in time and space has a strong stochastic component; for example, in some ways precipitation is random and erratic, whereas in other ways it appears to be well organized. Prediction in watershed hydrology not only involves the problem of divising suitable physical models, but also increases the demand for observations and analyses. Whereas a decade ago knowledge of the general pattern of precipitation over an area was regarded as sufficient, newer methods involve evaluation of quantities that depend upon the detailed precipitation field. Researchers in the field of watershed hydrology realize that further development of this discipline will require the improvement of both observation and prediction methods.

The authors of the chapters of this report have had considerable latitude in selecting and organizing their material for presentation. Any questions or comments regarding the programs described, the findings reported, and the status of data analysis should be addressed to the individual authors.

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Underscored numbers in parentheses refer to Literature Cited at the end of each paper. The data presented in the references are essentially used as they were supplied by the writer of each paper.

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AGRICULTURAL RESEARCH SERVICE PRECIPITATION FACILITIES AND RELATED STUDIES

CHAPTER 1.--WALNUT GULCH, ARIZ.

D. L. Chery and H. B. Osborn[1]

The rain gage network of the Walnut Gulch watershed is part of a comprehensive research program to (1) determine the future water yield potential of semiarid rangeland watersheds in the Southwest as related to measures for their conservation and sustained production of forage, (2) determine optimum utilization of water yield for local and downstream uses, and (3) obtain information needed for planning and designing measures for flash flood and sediment damage control. Within these general objectives, one study was concentrated on the precipitation received by the watershed.

The specific objectives of the precipitation study are—

1. To develop methods for evaluating rainfall amounts and rates for semiarid rangelands in the intermountain and high plains regions of the Southwest.
2. To determine seasonal distribution of precipitation for these areas.
3. To determine frequency of storms and expectancies of amount and areal extent for these areas.
4. To determine pertinent characteristics of rainfall with respect to runoff and sediment movement from these areas.

WATERSHED TOPOGRAPHY

Walnut Gulch is an ephemeral tributary of the San Pedro River, having their confluence near Fairbank, Ariz. The study area comprises the upper 58 square miles of the Walnut Gulch drainage basin. The watershed is a high foothill alluvial fan with materials ranging from clays and silts to well-cemented boulder conglomerates with little continuity of bedding. The topographic expression is that of gently rolling hills incised by a youthful drainage system. The area is representative of mixed grass-brush rangelands of southeastern Arizona and southwestern New Mexico. Altitudes above mean sea level range from 4,200 feet at the lowest gaging station to 6,000 feet at the upper end.

Figure 1 shows the locations of the 98 rain gages on the watershed.

Table 1 lists the elevation, type, recording chart scales, and a period of record history for each rain gage at the Walnut Gulch watershed.

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[1] Research hydraulic engineers, Southwest Watershed Research Center, 442 East Seventh Street, Tucson, Ariz. 85705.

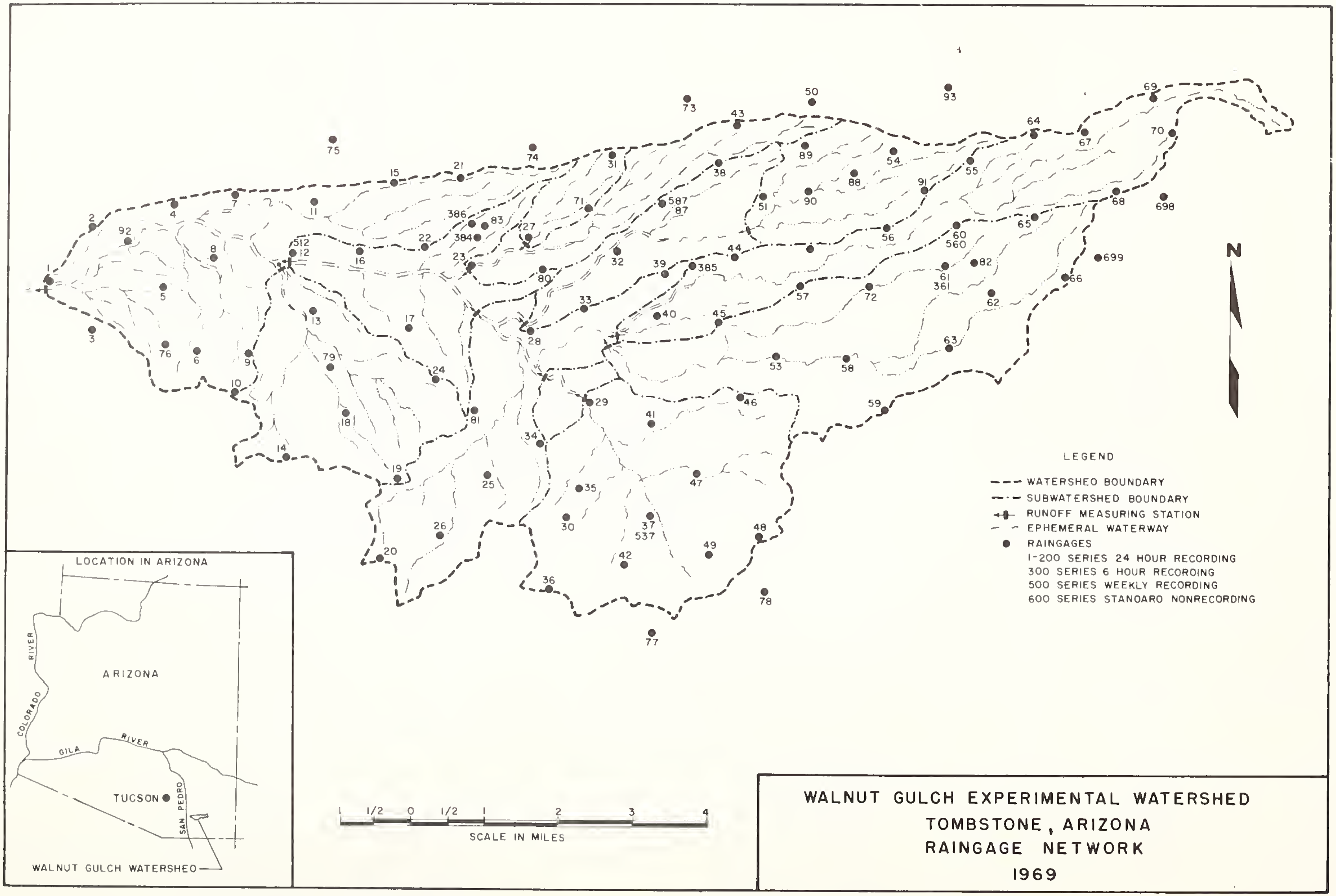

Figure 1.–Walnut Gulch Experimental Watershed, Tombstone, Ariz., rain gage network, 1969.

Table 1.–Rain gages at Walnut Gulch, Ariz., January 1970

Gage No.[1]	Elevation	Depth Scale	History	
		1″ = XX in. of rain	Gage installed	Periods of no record
	Feet[2]		*Dates*	*Dates*
63.001	4,047	0.333	7-8-54	
63.002	4,138	.333	7-15-54	
63.003	4,139	.333	7-15-54	
63.004	4,174	.333	7-15-54	
63.005	4,204	.333	7-17-54	
63.006	4,409	.333	4-27-62	
63.007	4,236	.333	7-15-54	
63.008	4,257	.333	7-15-54	
63.009	4,309	.333	7-15-54	
63.010	4,541	.333	7-15-54	
63.011	4,296	.333	7-15-54	
63.012	4,275	.333	7-8-54	8-57 to 1-60
63.013	4,371	.333	7-15-54	
63.014	4,521	.333	7-15-54	
63.015	4,423	1.000	7-05-56	
63.016	4,412	.333	7-15-54	
63.017	4.467	.333	7-28-65	
63.018	4,459	.333	7-15-54	
63.019	4,740	.333	7-15-54	1956 to 1962
63.020	5,011	.333	7-21-54	7-57 to 5-62
63.021	4,481	1.000	7-19-55	
63.022	4,450	.333	8-17-53	
63.023	4,402	1.000	7-08-54	
63.024	4,578	1.000	8-08-54	
63.025	4,673	.333	7-14-60	
63.026	4,892	.333	7-21-54	7-57 to 12-61
63.027	4,479	1.000	7-23-54	
63.028	4,514	1.000	4-04-56	
63.029	4,499	.333	7-20-54	
63.030	4,755	.333	7-19-55	
63.031	4,677	1.000	9-15-55	
63.032	4,561	1.000	2-26-62	
63.033	4,573	1.000	8-17-55	
63.034	4,658	.333	7-09-63	
63.035	4,632	.333	7-10-59	
63.036	4,808	.333	8-17-53	
63.037	4,674	.333	8-16-66	
63.038	4,785	1.000	7-27-60	
63.039	4,672	1.000	8-16-55	
63.040	4,588	1.000	7-05-62	
63.041	4,637	.333	9-14-55	
63.042	4,670	.333	9-14-55	
63.043	4,829	1.000	8-17-55	
63.044	4,742	1.000	8-16-55	
63.045	4,702	1.000	9-14-55	
63.046	4,723	1.000	10-5-62	
63.047	4,658	.333	9-14-55	
63.048	4,725	.333	9-14-55	
63.049	4,727	.333	7-25-60	
63.050	4,870	1.000	7-13-55	
63.051	4,815	1.000	1-26-61	
63.052	4,835	1.000	7-15-63	
63.053	4,644	1.000	3-02-67	
63.054	4,997	1.000	7-24-55	
63.055	5,119	1.000	7-29-60	
63.056	4,932	1.000	8-16-55	
63.057	4,804	1.000	6-15-59	
63.058	4,692	1.000	9-18-62	

See footnotes at end of table.

Table 1.—Rain gages at Walnut Gulch, Ariz., January 1970—Continued

Gage No.[1]	Elevation	Depth Scale	History	
		1" = XX in. of rain	Gage installed	Periods of no record
	Feet[2]		*Dates*	*Dates*
63.059	4,792	1.000	8-13-56	8-57 to 9-62
63.060	4,993	1.000	8-16-55	
63.061	4,939	1.000	3-06-57	
63.062	4,968	1.000	9-23-60	
63.063	4,810	1.000	1-04-61	
63.064	5,191	1.000	3-27-60	
63.065	5,076	1.000	8-16-55	
63.066	5,035	1.000	7-13-55	
63.067	5,265	1.000	1-03-61	
63.068	5,183	1.000	8-16-55	
63.069	5,354	1.000	1-23-57	
63.070	5,382	1.000	7-13-55	
63.071	4,580	1.000	2-08-60	
63.072	4,843	1.000	7-15-63	
63.073	4,771	1.000	6-29-61	
63.074	4,569	1.000	6-15-61	
63.075	4,403	1.000	6-14-61	
63.076	4,308	.333	5-31-61	
63.077	4,696	.333	7-26-61	
63.078	4,691	.333	6-30-61	
63.079	4,408	.333	4-17-64	
63.080	4,533	1.000	6-24-63	
63.081	4,631	1.000	2-19-62	
63.082	4,980	1.000	6-21-63	
63.083	4,517	1.000	7-01-63	
63.087	4,678	1.000	5-10-66	
63.088	4,921	1.000	5-10-66	
63.089	4,900	1.000	6-22-66	
63.090	4,791	1.000	7-01-66	
63.091	5,043	1.000	7-01-66	
63.092	4,113	.333	7-14-66	
63.093	5,053	1.000	8-08-67	
63.361[3]	4,939	.333	7-11-60	
63.384	4,504	.333	8-04-64	
63.385	4,685	.333	8-04-64	
63.386	4,494	.333	7-12-65	
63.512[4]	4,275	1.000	6-25-68	
63.537	4,674	1.000	6-25-68	
63.560	4,993	1.000	6-25-68	
63.587	4,678	1.000	6-25-68	

[1] All gages are the weighing-recording type. Time scale: 24 hours per revolution with 1 inch = 125.22 minutes, except as footnoted. The scales listed are those used currently.

[2] Feet above mean sea level (±10 feet).

[3] Rain gages Nos. 63.361, 384, 385, and 386 have a time scale of 6 hours per revolution with 1 inch = 31.30 minutes.

[4] Rain gages Nos. 63.512, 537, 560, and 587 have a time scale of 192 hours per revolution with 1 inch = 1,001.74 minutes.

DATA ACQUISITION AND PROCESSING PROCEDURE

Rainfall is sampled by a weighing rain gage with an orifice 8 inches in diameter. Each rain gage produces an analog recording of accumulated rainfall versus time. These analog records (charts) are normally removed from the rain gages once a week. When a chart is placed on a gage or removed from the gage, the time, as read from a wristwatch, is noted on the charts and a tick is made with the recording pen. Also, any additional information that would be useful in processing and interpreting the record is usually noted. The collected charts are then sent to the data processing center in Tucson. There the charts are checked and coded by a technician who classifies the precipitation event as significant (SS) or nonsignificant (NS). A significant event is one that causes runoff through any of the flow-measuring structures or has total rainfall of 0.25 inch with intensities greater than 0.50 inch per hour at one or more gages. This determination requires that all the records of a single event be examined as a group and the runoff records be consulted to determine the type of storm event. Once the type of event is determined, it is marked on the chart. The chart on and off times are checked, and any time corrections are distributed linearly throughout the period the chart was on the gage. Beginning times of events on the charts can be read to ±1 minute. The time base of the chart is also moved about as the chart creeps on the clock cylinder with changes in humidity. The chart can move out from under the retaining clamp 5 or 6 minutes (effectively extending the time base 5 or 6 minutes) within a week.

PROCESSING STATUS

The precipitation record for the entire period of record and for all gages has been completely processed by the procedure described in the following section and the data processed by a computer tabulation program, which produces a printed output and one tape output. The printed output (kept in the data library of the Tucson office) contains the following information:

1. For each precipitation event:
    - A. Watershed and rain gage identification
    - B. Date
    - C. Times [military (standard), elapsed, and increment]
    - D. Depths (accumulated and increment)
2. For significant precipitation events (see the next section for the definition of significant):
    - A. Rainfall intensity for each time increment
    - B. Maximum accumulated depths of rainfall per selected time interval
    - C. First moment about the beginning time of the rainfall histogram
3. Summation of daily rainfall amount by gage
4. Summation of monthly rainfall amount by gage
5. Summary tables (raw monthly and annual totals plus several weighted monthly and annual totals for the entire set of rain gages)

The contents of the printed output are a duplication of the output tape.

For missing records, beginning and ending times and total depths are estimated from an abbreviated isohyetal plot of the total recorded rainfall in gages surrounding the gage with the missing records. Any additional notes or marks on the chart are also used in making the estimate. The estimates are clearly labeled as such in the record. The charts are checked for skewed traces (a full vertical trace of the recorder pen that does not coincide with the time reference lines on the charts), and those that are detected are processed in a special way to compensate for deviation of the pen trace.

Before 1968, no regular infield calibration of the rain gages was made. Occasional checks of a rain gage measurement accuracy were made by measuring the water in the bucket of the gage in a standard rain gage tube. The standard tube measurement was written on the chart, and then consistent differences in the reading on the chart and the measured amount were used to determine the correction factor. Since 1968, each gage has been checked for weighing accuracy with a set of standard weights. The calibration standard is 823.00 ±0.01 gram equals 1 inch of water. The calibrations have been made in the field once each year with a calibration chart marked by a gage pen with the following sequence of calibrated weights—0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 3.50 inches, etc., to maximum.

The rain gage records are digitized with an analog to digital converter coupled with a card punch. Before beginning a shift, each operator is supposed to check the calibration of the equipment for the particular type of chart being read.

To read a chart, the operator places it on a chart reader screen and adjusts it with respect to reference marks on an overlay. The operator moves the reading lines to the beginning of the event, then sets the beginning time of the event, type of precipitation, significance code, card position code, time note, and depth note on the control console. The first reading is taken, and the position switch is set to indicate intermediate points. If the event has been classified as significant, the operator proceeds to make unequal interval breakpoint readings of the analog trace. Only beginning and ending points of a nonsignificant event are recorded unless the storm crosses midnight in which case an additional reading is taken at midnight. The nonsignificant events are usually not set up on the chart reader, but rather the operator reads the values and manually keypunches them.

The equipment can be scaled to read 0.01-inch depths and 2-minute increments on 12- and 24-hour-per-revolution charts and 1-minute increments on 6-hr./rev. charts. The machine specifications assure that it will count a value equal to ± 1 count. In addition, the preparation of the overlay reading lines influences the accuracy of reading values from the charts. In general, the prepared overlays will read the time values with no increase in error, but deviations on depth readings increase by another ± 1 count, resulting in a depth reading of 0.01 inch ± 0.02 inch.

The data in punchcard format are then loaded on magnetic tape and processed by a checking program that checks for more than 50 logical or possible error situations. A list of the data, with the errors noted, is printed, from which corrections are prepared. Corrections to the tape are keypunched, and the data tape is corrected by an updating program. After the corrections have been made and confirmed, the data are processed by a tabulation program, which provides a printed output and one tape output.

COMMENTS ON THE GAGE-PROCESSING SYSTEM

The processed precipitation information is prepared from records gathered on two types of rain gages with three different time bases (6 hr./rev., 24 hr./rev., and 192 hr./rev.). Each gage-clock combination has a different resolution of the depth and time measurement. In addition to the performance of an individual gage, the entire network of gages must also be considered in the ensemble. There is no common time base among the gages. The time of each is set approximately once a week with reference to a technician's wristwatch. Because of the time resolution of the 24-hour charts and the use of the wristwatch, time at one gage at any one instance will be, at best, in phase ± 5 minutes with any other gage in the network. Gages can be in phase or up to 10 minutes out of phase. This estimate is based on experience with the system and the procedures. No objective evaluation has been made of this source of error.

Because the charts of the 6- and 24-hour gages are changed once a week, many pen traces are superimposed. As a consequence, many small events (0.01- to 0.05-inch total depth) are masked by overlapping or heavy pen traces and are sometimes not recorded in the digital record. This problem was particularly evident to W. D. Sellers (Institute of Atmospheric Physics, University of Arizona, Tucson) when he compared hourly rainfall amounts of 12-hr./traverse gages at Safford (45.002, 45.004, 45.009, and 45.015) and weekly recording gages elsewhere in Arizona. Dr. Sellers found that for the January to February period, 0.01-inch hourly rainfall amounted to 22 percent of the period total at the ARS Safford gages, whereas for the rest of Arizona, it was 39 percent of the period total. The distribution of the other amounts was similar. For the summer period, July to August, the differences were even greater. The 0.01-inch hourly amount was 6 percent of the period total at Safford; for the rest of Arizona it was 28 percent of the period total. The 0.02-inch hourly amount was 7 percent of the period total at Safford and 14 percent of the period total for the rest of Arizona. The two distributions cross between 0.03- and 0.04-inch hourly amounts, and the ARS record continues to rise until it peaks at approximately 9 percent for 0.06-inch hourly amount and then decreases asymptotically to the distribution for the rest of Arizona.

Because of the differences in the shape of the distributions, the magnitudes at the low hourly amounts, and experience with the actual records and processing procedure, many 0.01- to 0.05-inch rainfall events may not have been recorded.

Since 1967, all estimates have been noted in the record. As the data are processed by the tabulation program, a tally is made of the amount estimated in the record for each gage. This information is used to evaluate the quality of the record and to advise the field crews which gages need servicing or how procedures should be improved. Table 2 lists the rain gages at Walnut Gulch for which more than 10 percent (in either rainfall duration or accumulated depth) of the record had to be estimated. Records before 1967 probably have a greater amount of estimation than those of 1967. As is evident from table 2, some improvement in the records has been obtained from the rain gages. However, problems continue to occur despite the efforts of a conscientious field crew. Management problems can be improved by having regular calibration checks (as were begun in 1968) and a feedback of information to the field crews to correct faulty instruments or procedures. There is little possibility of improving the problems intrinsic in such a system. With the type of manual-mechanical rainfall recording system being operated, there is an irreducible amount of opportunity for error or malfunction.

Table 2.–Rain gages at Walnut Gulch, Ariz., for which 10 percent or more of the record was estimated

1967			1968			1969		
Gage No.	Duration estimation	Depth estimation	Gage No.	Duration estimation	Depth estimation	Gage No.	Duration estimation	Depth estimation
2	12	3	6	9	11	6	11	9
12	1	12	24	19	9	9	12	1
16	14	7	25	23	14	10	12	2
17	12	12	34	13	7	16	11	2
24	38	25	50	13	0	22	9	14
26	8	12	58	20	12	24	15	3
28	6	26	65	10	5	35	10	6
29	21	17	68	15	8	36	7	13
33	5	10	75	4	13	42	8	14
36	32	13	77	10	11	46	17	4
69	7	10	90	19	8	49	15	14
75	28	19	92	16	6	50	9	11
76	3	10	537	9	15	53	14	4
79	16	15				56	12	16
82	23	12				60	9	10
87	59	24				67	25	18
89	36	16				69	11	3
93	55	26				77	21	13
						87	16	21
						384	14	6
						385	40	7
						386	14	6

PRECIPITATION AND CLIMATOLOGY IN SOUTHERN ARIZONA

The following description is quoted directly from “Arizona Climate”[4]:

> “During the cooler half of the year most of Arizona’s precipitation is associated with large-scale cyclonic storms embedded in the prevailing westerlies which gird the earth between 25°N and 60°N latitude and reach maximum velocities in excess of 100 miles per hour at 30,000 to 40,000 feet above sea level. Over the United States in winter these westerlies and their accompanying storms normally follow a path around the north side of a semipermanent ridge of high pressure off the west coast, entering the continent in northern Oregon and Washington. They then pass southward around a trough of low pressure centered in the Hudson Bay area, following a path which usually takes them along the lee (eastern) side of the Rockies (where they often strengthen or intensify) through the central Great Plains region, and then northeastward through the St. Lawrence River Valley to the Atlantic Ocean. Under these normal conditions, winter storms seldom produce more than partly cloudy skies and strong winds in Arizona.
>
> “Summer precipitation is definitely of a showery nature, starting abruptly, continuing intermittently for a brief period, usually less than half an hour, then slowly tapering off until ceasing altogether. These showers, often accompanied by thunder and lightning, are most common and most intense over the mountainous sections of the state, where the combined effects of thermal heating and orographic uplift, as well as convergence of air on the windward side of the mountain ranges, favor the setting off of strong vertical currents. Over the flat desert sections showers are normally light, usually being completely overshadowed by the strong winds and blowing sand by which they are accompanied. It has been estimated from hourly

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[4] Sellers, W. D. Arizona climate. Inst. Atmos. Phys., Univ. Ariz., Tucson. 260 pp., illus. 1960.

precipitation data that certain sections of Arizona average better than one thunderstorm per day in July and August. These include the hilly country in the extreme southeastern corner of the state and the southern slopes of the White Mountains. The latter area may experience between eighty and ninety thunderstorms during the two midsummer months.

"There is a very marked diurnal variation in the occurrence of precipitation in summer, with a maximum in the late afternoon and a minimum in the morning, usually after sunrise. This reflects the strong influence of thermal heating, which shows a similar diurnal variation, on the summertime precipitation regime. However, it may be that the convergence of drainage winds near the earth's surface also plays an important role in some areas. These winds normally blow upslope during the day, with maximum speeds being reached in the midafternoon, and downslope at night, with the maximum speeds in the early morning. In regions where the winds in the free atmosphere are light, such as in Arizona in summer, these local wind systems must be very important in establishing the low-level convergence field.

"Practically all of the moisture for Arizona's summer precipitation is drawn into the state from the Gulf of Mexico and the Atlantic Ocean. However, this is not always the case. In fact most of the *record* summer rains in the past century have been associated with deep surges of tropical air into the state from the Gulf of California and the Pacific Ocean. These storms, which occur most frequently in late August and September, usually originate as tropical hurricanes off the west coast of Mexico. As they move northward, they weaken considerably, sometimes to the point of disappearing altogether. However, perhaps once every four or five summers, when conditions are right, a tropical storm may come rampaging through Arizona, accompanied by gale-force winds and flood-producing rains. What the "right conditions" are is not exactly clear. It has not even been definitely established that these storms always originate as tropical hurricanes, although in most cases they do.

"Drought conditions are most common in Arizona in May and June. The southwest section is almost bone-dry during these months, receiving measurable amounts of precipitation in less than one year out of three. All parts of the state are affected by this late spring drought, with even the relatively moist central and plateau sections going without rain in one month or the other in about one year out of every four.

"Unusually dry weather also occurs in Arizona in the fall, perhaps the most pleasant season of the year. This dry spell is most pronounced in October in the southern half of the state and in November in the northern half. The fall drought is much less severe than that of spring, the southwest section normally going without measurable precipitation in either October or November in only two years out of every five."

PRECIPITATION ON WALNUT GULCH

Since 1904, annual precipitation at Tombstone has averaged 14.5 inches and has ranged from 7.36 inches in 1924 to 27.84 inches in 1905. Similar, although less pronounced, variation has been observed in a single year among the network of rain gages maintained on the Walnut Gulch watershed. The average annual rainfall over the entire 58-square-mile watershed has ranged from 7.1 to 14.2 inches with a mean of 11.3 inches for 1955-56.

The year's precipitation falls during two distinct periods with greatly differing characteristics. Winter precipitation, amounting to one-third of the annual total, occurs as snow or rain of wide areal extent and low intensity. Runoff has never been recorded from winter storms except on very small areas. Most of the remaining two-thirds of the precipitation falls during July, August, and September as a result of intense convective thunderstorms of limited areal extent. Practically all runoff results from this type of storm. Of the runoff-producing portions of these summer storms, 80 percent have been observed to cover 4.5 square miles or less within the confines of the Walnut Gulch watershed; however, this includes many storms falling on the edge of the area, with portions of their extent not measured.

REFERENCES

Publications or other references that have used information from the rain gage network of Walnut Gulch are listed below. Conclusions and information derived from the rain gage network can be found in the abstracts following each reference as appropriate.

(1) Amisial, R. A.

1969. Analog computer solution of the unsteady flow equations and its use in modeling surface runoff process. [Unpublished Ph. D. diss. Copy on file at Utah State Univ., Logan.]

(2) Fletcher, Joel E.

1960. Characteristics of precipitation in the rangelands of the Southwest. Proc. Joint Agr. Res. Serv. – Soil Conserv. Serv. Hydrol. Workshop, New Orleans.

(3) Hershfield, D. M.

1965. On the spacing of rain gages. Bul. Internatl. Assoc. Sci. Hydrol. Pub. 67: 72-79.

The "key" gage principle was found not to be applicable to the Walnut Gulch watershed.

(4) Hickok, R. B., Keppel, R. V., and Rafferty, B. R.

1959. Hydrograph synthesis for small arid land watersheds. Agr. Engin. 40(10): 608-611.

This paper presents a method of hydrograph synthesis developed especially for small arid land watersheds. The method involves (a) estimating a characteristic lag time from readily determined watershed parameters, (b) using the watershed lag time to predict the hydrograph peak rate for an assumed total volume of runoff, and (c) synthesizing the entire hydrograph using the lag time, the estimated peak rate, and a standard dimensionless hydrograph.

Development of the method is based on the analysis of rainfall and runoff records for 14 experimental watersheds in Arizona, New Mexico, and Colorado. Data from the Walnut Gulch watershed were used to check the validity of the method.

(5) Keppel, R. V., and Gardner, J. L.

1964. Walnut Gulch experimental watershed. Agr. Expt. Sta., Univ. Ariz., Tucson. 15 pp.

(6) Kincaid, D. R., Gardner, J. L., and Schreiber, H. A.

1964. Soil and vegetation parameters affecting infiltration under semiarid conditions. Bul. Internatl. Assoc. Sci. Hydrol. Pub. 65: 440-453.

On subwatersheds of the Walnut Gulch Experimental Watershed, measurements of precipitation and runoff showed extreme variation in the rainfall-runoff relation. This variation is attributed to irregularity of amount, intensity, and distribution of the precipitation and to unmeasured differences among the subwatersheds.

To ascertain effects of soil on infiltration, rain gages and Bouyoucos moisture blocks were installed on a 4.5-acre, grass-covered drainage area of igneous soil and on a 3.0-acre drainage area of calcareous soil supporting a shrub cover. Soil in the grassland area showed greater and more abrupt responses to rainfall at the 6- and 18-inch depths. Moisture depletion at the 6-inch depth was more rapid in the grassland area, indicating more rapid evaporation or more complete root permeation of the upper soil or a combination of these two conditions. Moisture withdrawal from the 18-inch depth was about the same on the two areas. Pits dug through the soil profile showed little root penetration below the 20-inch depth on either area.

To determine the relation of infiltration to different factors in the soil-vegetation complex, infiltrometer tests were made with a Type-F infiltrometer on randomly selected 6- x 12-foot plots. Cumulative short-time infiltration

increased with surface gravel. Crownspread of shrubs appeared to be more closely related to infiltration than any other single parameter of vegetation. The combination of the shrub and half-shrub over-story with ground cover of surface gravel, litter, and grass showed the best observed relation to cumulative short-time infiltration; and a fair curvilinear relation was demonstrated between crownspread of shrubs and half-shrubs and final infiltration capacity.

(7) Kincaid, D. R., Osborn, H. B., and Gardner, J. L.
1966. Use of unit-source watersheds for hydrologic investigations in the semiarid Southwest. Water Resources Res. 2(3): 381-392.

The unit-source watershed is an intermediate step between plots, in which certain runoff generative processes can be isolated. For large watersheds, the yields are controlled by the hydraulics of their complex channel systems. Several unit-source watersheds have been instrumented within the Walnut Gulch experimental watershed in southeastern Arizona. Their comparative data indicate some basic hydrologic relationships between net runoff and size of drainage area, the significance of storm patterns, the relation of runoff and sediment yield to vegetational cover, and hydrograph characteristics.

(8) Kwan, John Y., Riley, J. P., and Amisial, R. A.
1968. A digital computer program to construct isohyetal maps and calculate volumes of precipitation. Bul. Internatl. Assoc. Sci. Hydrol. 1(8): 240-248.

A Fortran IV program has been developed to construct isohyetal lines from precipitation data of given stations. Points on the isohyetal lines are determined by linear interpolation between stations. Once the isohyetal points were obtained, their proper sequence was determined by starting with a certain point and checking the points successively nearest to it for a permissible connection between the two points. Then the sequence of points was checked for possible looping or connection with other sequences of points of the same precipitation. The isohyetal lines were then smoothed by successive parabolic approximations.

Volume of precipitation can be calculated within any specified boundary, such as subzones of a given area, by summing the product of the area between two precipitation lines and the average precipitation value of the lines. The area between the isohyetal lines is found by dividing the region into straight line trapezoidal segments and summing the areas of the trapezoids.

(9) Osborn, H. B.
1964. Effect of storm duration on runoff from rangeland watersheds in the semiarid Southwestern United States. Bul. Internatl. Assoc. Sci. Hydrol. IX(4): 40-47.

Almost all runoff from the semiarid rangelands of the Southwestern United States results from intense convective storms of short duration. Depth-duration values for precipitation for this region that are developed through standard procedures may be misleading when used for runoff design. Various combinations of short bursts of rain can, and do, plot on average depth-duration curves, but such curves have little practical meaning for small watersheds (100 square miles or less). For the design of small watersheds, depths of precipitation for relatively short periods (15, 30, or 60 minutes) for varying return periods and areas are needed. For runoff design for larger watersheds two probability estimates may be needed--the probability of storms of certain intensities and size falling on tributary watersheds of finite sizes, and the probability of storms developing over a multitributary system in such patterns as to produce important volumes and peaks of runoff.

(10) ———
1967. Variations in precipitation from thunderstorms in the Southwest. Proc. 5th Conf. on Severe Local Storms, Amer. Met. Soc., St. Louis, Mo., pp. 219-225.

(11) ———
1968. Persistence of summer rainy and drought periods on a semiarid rangeland watershed. Bul. Internatl. Assoc. Sci. Hydrol. XIII (1): 14-19.

In southeastern Arizona, almost all summer rainfall results from widely scattered high-intensity afternoon or evening thunderstorms of limited areal extent. For 11 years of record on the Walnut Gulch Experimental Watershed, Tombstone, about 70 percent of the annual rainfall of 11½ inches and over 95 percent of the annual runoff occurred in July, August, and early September. In contrast, about 5 percent of the rainfall occurred in the previous 3 months, and about 25 percent in the remaining 6½ months.

Therefore, summer rainfall, although highly variable, represented the most dependable source of water to the Walnut Gulch watershed. On the average, significant rainfall was recorded on some part of the watershed on 40 percent of the days in the critical July-August period. The maximum frequency was 3 out of every 4 days in 1955, and the minimum was 3 out of every 10 days in 1960.

The wettest year was 1955, with a continuous rainy period of 47 days; whereas the driest was 1960, with the longest rainy period lasting only 5 days. The longest summer drought during the period of record occurred in 1962, when no rain fell for 17 days in August, following a 14-day rainy period in late July.

As yet, there are not enough data to determine reliable expectancies for summer rainy or drought periods.

(12) Osborn, H. B. and Hickok, R. B.
1968. Variability of rainfall affecting runoff from a semiarid rangeland watershed. Water Resources Res. 4(1): 199-203.

On the 58-square-mile Walnut Gulch watershed in southeastern Arizona, summer precipitation is characterized by intense thunderstorms of limited areal extent; winter precipitation, usually rain, is characterized by low-intensity storms of wide areal extent. For 11 years of record from 30 recording gages, about 70 percent of the annual precipitation of 11.22 inches occurred in the summer months June through September. Summer precipitation exceeded winter precipitation in each of the 11 years of record. Average annual precipitation varied from 7.1 to 14.2 inches for the period of record. During the same period, point precipitation varied from slightly under 5 inches to slightly over 20 inches. The lowest annual point precipitation was about 50 to 60 percent of the highest. Significantly more summer rainfall was recorded on the highest elevations than on the lowest, which indicated an effect of elevation on precipitation. However, the most summer rainfall, for the 11-year period of record, was recorded near the center of the watershed, which indicated possible topographic influences other than watershed elevation. Annual runoff from Walnut Gulch varied from 0.02 inch (1 acre-foot per square mile) to 1 inch (53 acre-feet per square mile). For the same period on 1-square-mile subwatershed, annual runoff varied from 0.02 inch (1 acre-foot per square mile) to about 6 inches (320 acre-feet per square mile).

(13) ____________ and Lane, L.
1969. Precipitation-runoff relationships for very small semiarid rangeland watersheds. Water Resources Res. 5(1): 419-425.

Simple linear regression models for predicting total volume of runoff, peak rate of runoff, duration of runoff, and hydrograph lag-time were developed using 3 years of data from four small (0.56 acre to 11.0 acres) watersheds. The models developed indicated that runoff volume was most strongly correlated to total precipitation; that peak rate of runoff was most strongly correlated to the maximum 15-minute depth of precipitation; that flow duration was most strongly correlated to watershed length; and that lag time was most strongly correlated to watershed area. These independent variables accounted for 70, 70, 50, and 30 percent, respectively, of the variance in the predicted variables. The exponential decay form of the antecedent precipitation equation accounted for 8 percent of the variation in runoff on one watershed but was insignificant on the others. Analysis indicates that the data represent the high frequency events. It is possible that these models will not accurately predict the low frequency events.

(14) ____________ Lane, L. J., and Hundley, J. F.
1970. Optimum rain gage densities in semiarid regions of the Southwest. (Submitted for publication in Water Resources Research)

For satisfactory representation of thunderstorm rainfall in southeastern Arizona without regard to runoff, the optimum rain gage density would require rain gages to be located at 1,000-foot intervals. This would amount to about 1,400 gages for a 58-square-mile watershed. For correlating rainfall and runoff on finite-sized watersheds, the following optimum gaging densities were determined:

(a) One centrally located rain gage for watersheds up to about 120 acres in size is adequate.
(b) Three evenly spaced gages are needed for a 1-square-mile watershed with a length-width ratio of 4.
(c) A network of five evenly spaced gages is required for a more or less circular 10-square-mile watershed. This network amounts to a network of gages spaced at about 1.5-mile intervals.

Since runoff-producing thunderstorm rainfall is limited in areal extent and since ephemeral sand channels abstract large volumes of runoff, direct correlation between rain gage networks and runoff decreases rapidly for watersheds larger than 10 square miles. Therefore, runoff from such watersheds as Walnut Gulch must be calculated from runoff determinations from the subunits within the watershed and from estimates of the channel abstraction between these subunits and the main watershed outlet. Therefore, to correlate rainfall and runoff from the watershed requires a network of gages similar in density to that for W-5 at about 1.5-mile intervals. This would amount to about 40 evenly spaced rain gages for the 58-square-mile Walnut Gulch watershed.

(15) Osborn, H. B. and Keppel, R. V.
1966. Dense rain gage networks as a supplement to regional networks in semiarid basins. Bul. Internatl. Assoc. Sci. Hydrol. 68: 675-687.

Because of their small size, widely scattered distribution, and short duration, convective thunderstorms typical of the Southwestern United States and many other semiarid regions can best be described by data gathered from dense recording rain gage networks on sufficiently large areas. Data are presented from two such networks—one of 60 recording gages located on a 67-square-mile area in eastern New Mexico, and one of 80 recording gages on 58-square-miles in southeastern Arizona—showing depth-area and intensity-duration characteristics for convective thunderstorms. Comparisons are made between the frequency relationship computed from the long-time record at a point and that from a few years of dense network records based on the station-year concept. A storm on the eastern New Mexico area with exceptionally high intensities for durations up to 30 minutes is discussed.

(16) ____________ and Renard, K. G.
1969. Analysis of two runoff-producing Southwest thunderstorms. Jour. Hydrol. 8(3): 282-302.

The two largest runoff-producing storms for 10 years of records, the first in 1964 and the second in 1967, recorded on the Walnut Gulch Experimental Watershed in southeastern Arizona are analyzed and compared. Both storms were nonfrontal thunderstorms which produced peak discharges on the order of 1,500 c.f.s. per square mile; in 1964, from a 2,000-acre subwatershed, and in 1967 from an 84-acre subwatershed. During the 1967 storm, rainfall of 3.35 inches in 45 minutes was recorded at one point on the watershed and approximately 18 acre-feet of runoff was produced on the 84-acre subwatershed. Runoff-producing rainfall lasted for less than 60 minutes for both storms. For both storms, runoff per unit area decreased with increasing subwatershed size because of the large transmission losses in the ephemeral channels and because of the limited areal extent of the runoff-producing rainfall.

(17) ____________ and Reynolds, W. N.
1963. Convective storm patterns in the Southwestern United States. Bul. Internatl. Assoc. Sci. Hydrol. 8(3): 71-83.

In the Southwestern intermountain and high plains areas, precipitation is seasonal, with the major part of the rainfall occurring in the summer. Most winter precipitation occurs as low-intensity rain or snow along slow-moving cold fronts. Most summer precipitation occurs as short-duration, high-intensity thunderstorms from purely convective buildup or from convective cells developing along a weak fast-moving cold front. Almost all runoff occurs from the summer convective storms.

Since runoff-producing precipitation is of primary interest at the Southwest Watershed Research Center, Agricultural Research Service, Tucson, the convective storms have been most thoroughly analyzed. Duration, intensity, areal extent, movement, character, and return periods for varying volumes and intensities of these convective storms are analyzed from records from dense networks of recording rain gages in four study areas in Arizona and New Mexico. The primary study areas are the 58-square-mile Walnut Gulch Experimental Watershed at Tombstone and the 67-square-mile Alamogordo Creek Watershed near Santa Rosa, N. Mex. Three “record” storms of differing character occurring in 1960 and 1961 on Alamogordo Creek Watershed and one record storm in 1961 on the Walnut Gulch Watershed are analyzed and compared in detail.

(18) Renard, K. G.
1970. The hydrology of semiarid rangeland watersheds. U.S. Dept. Agr., Agr. Res. Serv., ARS 41-162, 26 pp.

The hydrology of semiarid areas in the Southwest is characterized by (1) high intensity, limited areal extent precipitation; (2) limited soil moisture; (3) sparse vegetation; (4) high evaporation; (5) high transmission losses; and (6) low annual surface water yield. The surface water yield per unit area decreases rapidly with increasing watershed area as a result of the transmission losses.

(19) Renard, K. G. and Osborn, H. B.

1966. Rainfall intensity comparisons from adjacent 6-hour and 24-hour recording rain gages. Water Resources Res. 2(1): 145-146.

On the Walnut Gulch Experimental Watershed near Tombstone, Ariz., precipitation intensities at four locations were measured with adjacent recording rain gages having 6-hour-per-revolution and 24-hour-per-revolution time scales. Maximum intensities determined from the 6-hour gage records were found to be significantly greater than intensities determined from the 24-hour gage records for intervals up to 10 minutes.

(20) Schreiber, H. A., and Kincaid, D. R.

1967. Regression models for predicting on-site runoff from short-duration convective storms. Water Resources Res. 3(2): 389-395.

On-site runoff resulting from summer convective thunderstorms was studied in the Walnut Gulch Experimental Watershed, using 6- x 12-foot plots at two locations, based on 5 location-years of data from 34 storms. Average runoff increased as precipitation quantity increased, decreased as crown spread of vegetation increased, and decreased as antecedent soil moisture increased. In a stepwise multiple linear regression equation, these independent variables accounted for, respectively, 72, 3, and 0.5 percent of the prediction variance. Considering regression equations for any one location-year, storm amount or intensity always was significant, crown spread usually was significant, and antecedent soil moisture rarely was significant. In simple correlations, antecedent soil moisture was never related significantly to runoff. The equations developed appear valid for a set of thunderstorms with at least one-sixth of maximum 5-minute intensities exceeding 3.7 inches per hour.

(21) Southwest Watershed Research Center.

1967. Walnut Gulch Experimental Watershed. Brochure, 22 pp., Tucson, Ariz.

CHAPTER 2.--VERO BEACH, FLA.

W. C. Mills[1]

Precipitation studies conducted on three experimental watersheds in the vicinity of Vero Beach, Fla., constitute an integral part of a larger study to evaluate overall hydrology of these watersheds. Such an evaluation is designed to provide hydrologic information vital to the development, control, and efficient use of water resources throughout central and southern Florida, which is rapidly developing its agriculture.

A specific objective of the precipitation studies is to determine amounts and distribution properties of precipitation input to the Vero Beach experimental watersheds to evaluate the effects of these properties on other phases of the hydrologic process.

An additional objective is to document consistent patterns of rainfall distribution, both temporal and spatial, for estimating rainfall patterns for other areas in central and southern Florida.

TOPOGRAPHY AND GEOGRAPHICAL LOCATION

Topography of the experimental watersheds and surrounding area is nearly flat, with landslopes ranging largely from 0 to 2 percent. Watershed W-1, an area of 78 square miles, is located on the Atlantic Coast and includes a portion of the city of Vero Beach. Watershed W-2 (including subarea W-3) is 29 miles southwest of W-1 and about 3 miles north of Lake Okeechobee; it is the upper 98.7 square miles of Taylor Creek Basin. Watershed W-4 is an area of 6.20 square miles located adjacent to the St. Lucie Canal about 35 miles south of W-1 and 35 miles southeast of W-2.

Figures 1, 2, and 3 show the locations of the experimental watersheds and corresponding rain gage networks.

Table 1 gives gage type, approximate elevation, and date record began for gages on the three Vero Beach watersheds.

Table 1.–Rain gage networks, Vero Beach, Fla.

Watershed and gage No.[1]	Elevation above mean sea level	Record began[2]
	Feet	*Date*
W-1:		
1	21	4-1-51
2	21	4-1-51
3	24	4-1-51
4	20	1-1-56
5	21	4-1-51
W-2:		
1	65	7-1-55
2	45	7-1-55
3[3]	36	7-1-55
4	65	7-1-55
W-2–Continued		
5	33	7-1-55
6	34	7-1-55
7	34	7-1-55
W-4:		
1	23	1-1-59
2	23	1-1-59
3	23	1-1-59
4	24	1-1-59
5	24	1-1-59

[1] All gages are the recording-weighing type except as footnoted.
[2] All gages are currently in operation.
[3] Standard 8-inch U.S. Weather Bureau nonrecording gage and recording gage at same location.

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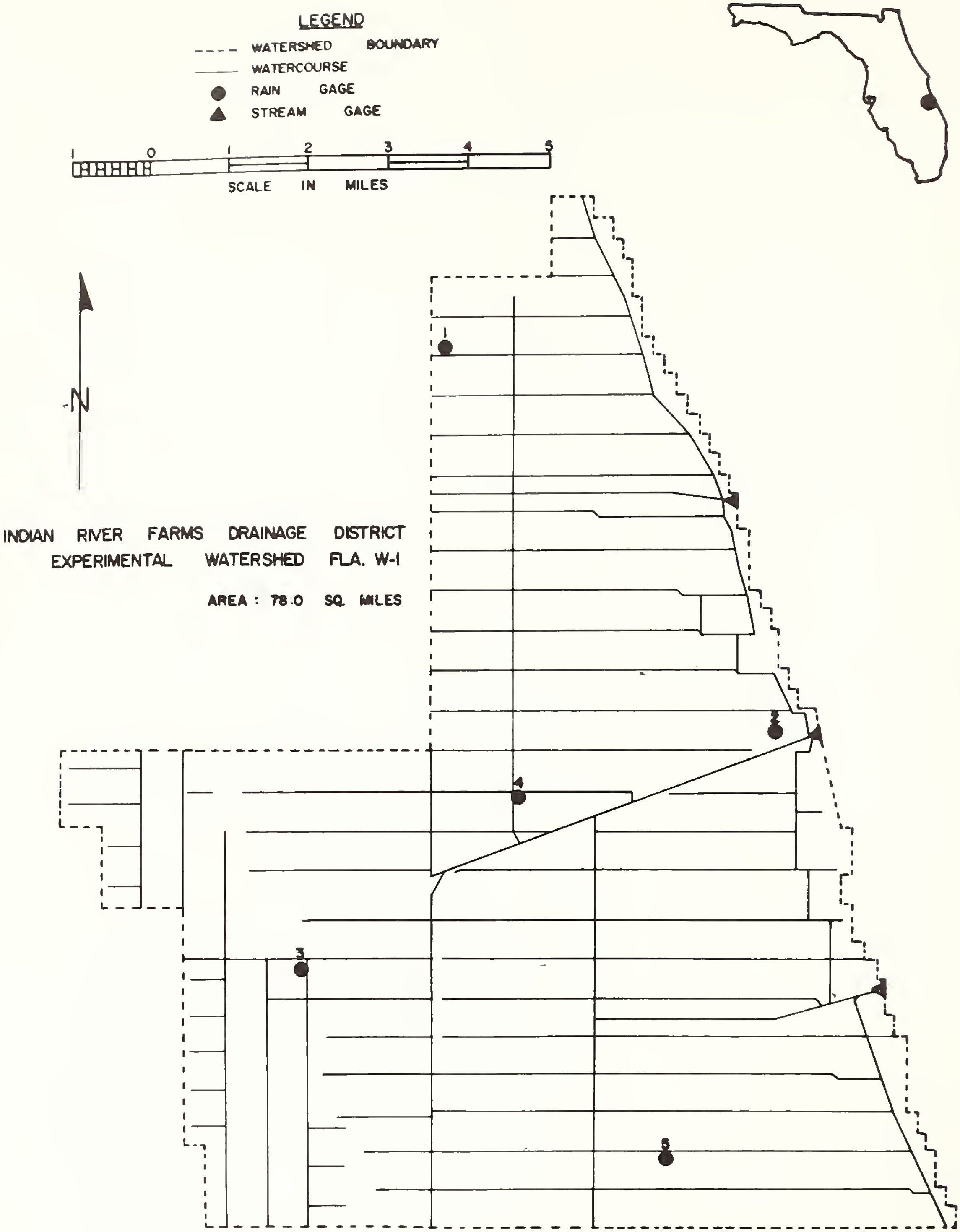

Figure 1.–Rain gage network W-1, Vero Beach, Fla.

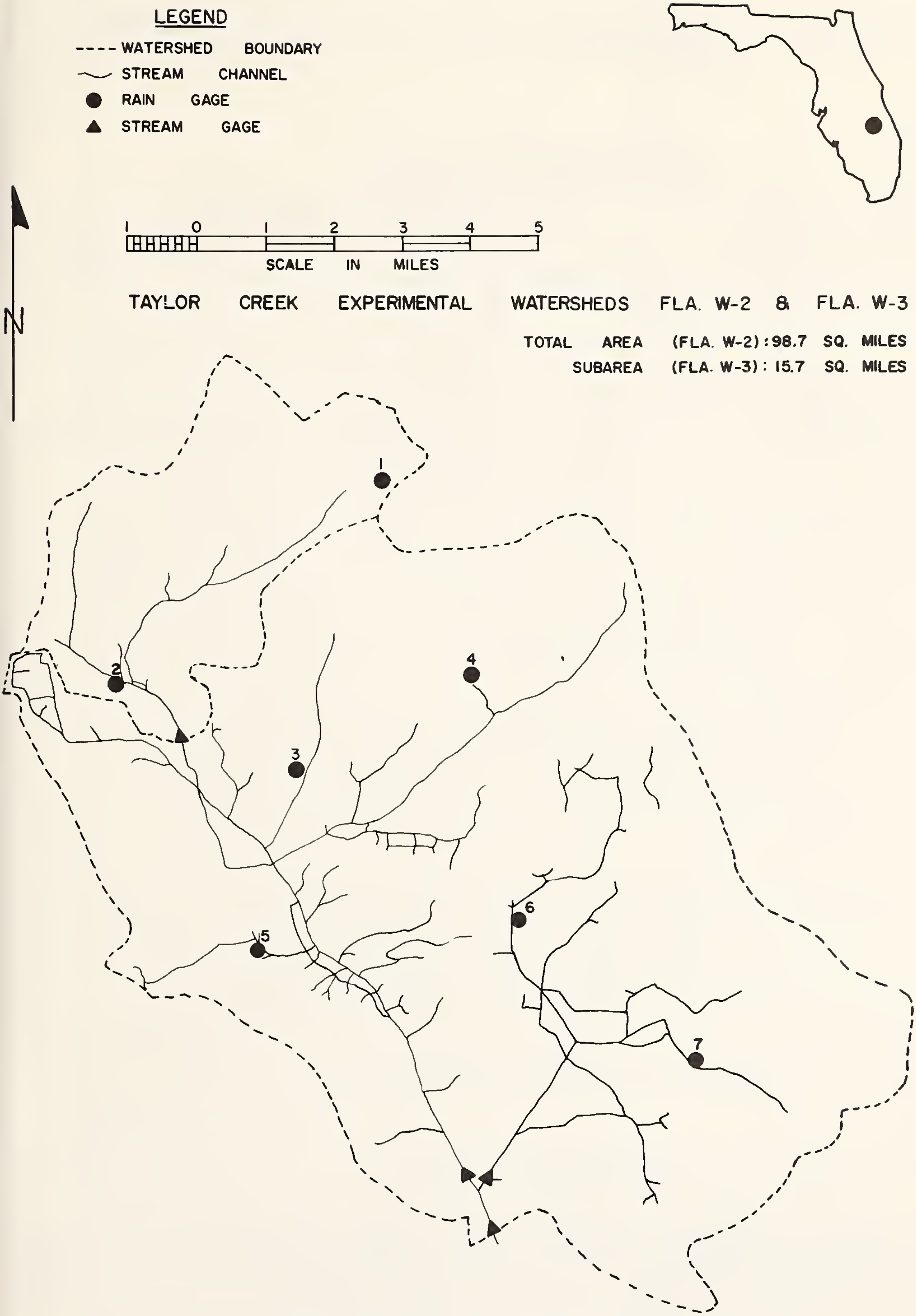
LEGEND
WATERSHED BOUNDARY
STREAM CHANNEL
● RAIN GAGE
▲ STREAM GAGE
N
1 0 1 2 3 4 5
SCALE IN MILES
TAYLOR CREEK EXPERIMENTAL WATERSHEDS FLA. W-2 & FLA. W-3
TOTAL AREA (FLA. W-2): 98.7 SQ. MILES
SUBAREA (FLA. W-3): 15.7 SQ. MILES
1
2
3
4
5
6
7

Figure 2.—Rain gage networks W-2 and W-3, Vero Beach, Fla.

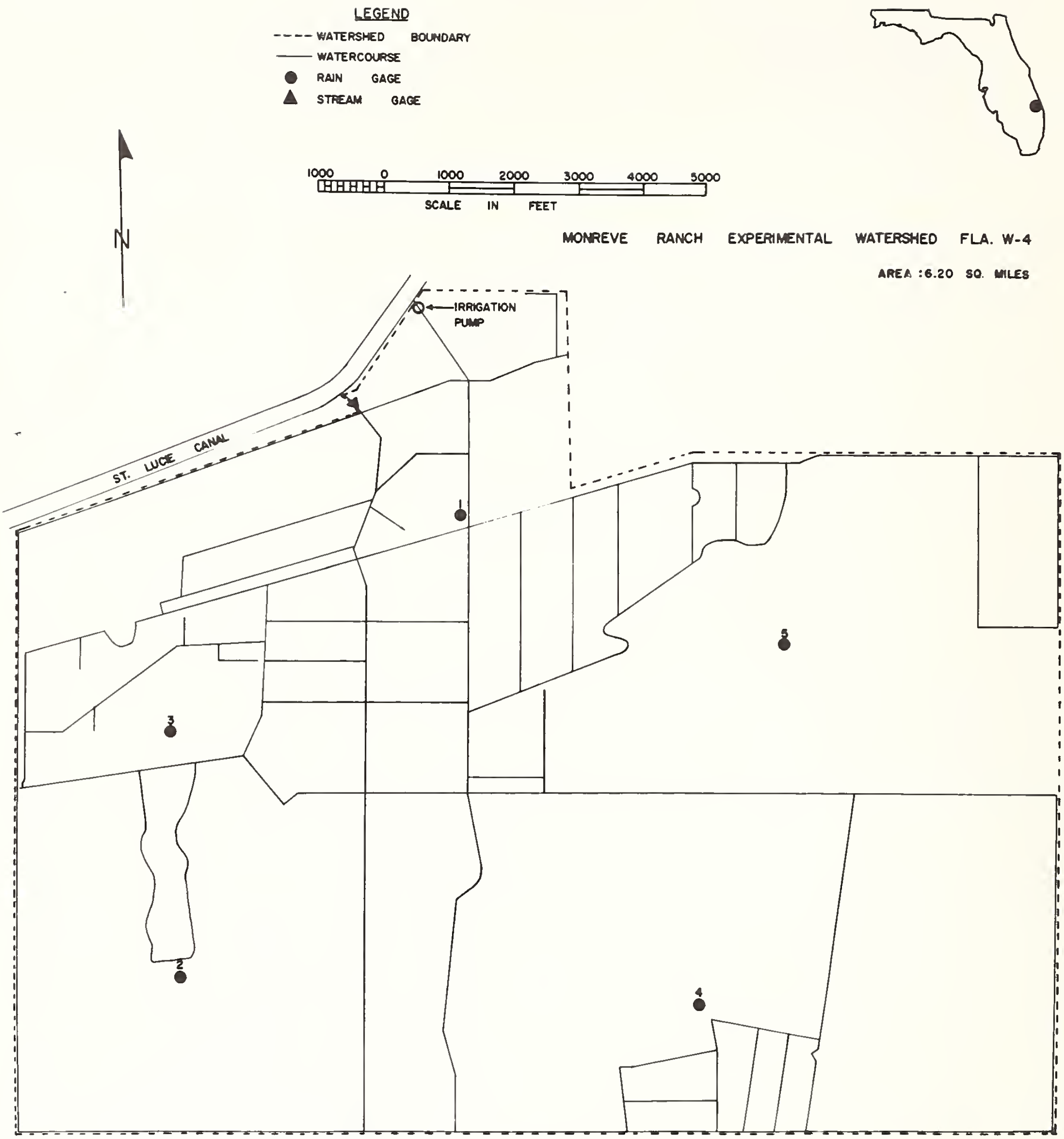

Figure 3.–Rain gage network W-4, Vero Beach, Fla.

PROCESSING OF DATA

Precipitation on the Vero Beach experimental watersheds is recorded in analog form on 8-day strip charts, which are changed weekly. Daily precipitation amounts are read from the charts and recorded in tabular form. Daily values from individual gages are Thiessen-weighted to obtain daily rainfall for each watershed; these values are then tabulated along with the individual gage amounts. To provide for computer processing and analysis, daily rainfall amounts for each gage are punched on cards along with other pertinent hydrologic data from the watersheds. The data are recorded on magnetic tape in the same format as for the cards, providing for computer input requirements of either cards or magnetic tape.

For selected gages on watershed W-2, intensity breakpoints are obtained from the strip charts, and rainfall amounts and corresponding time intervals are punched on cards. In addition, for special studies, hourly rainfall for all gages on W-1 and W-2 is tabulated for selected storm durations.

PRECIPITATION CLIMATOLOGY

Precipitation on the Vero Beach experimental watersheds occurs almost exclusively as rainfall. Mean annual rainfall is 53 inches for the two watersheds near the Atlantic Coast (W-1 and W-4) and 48 inches for the inland watershed (W-2).[2] The greater portion of annual rainfall normally occurs during June through October (62 percent for the coastal areas and 65 percent for the inland watershed). Most extreme rainfall events occur during this period, and many of them are associated with hurricanes. November through February is usually dry; only 14 to 18 percent of the total annual rain falls during this period. During March through May, rainfall amounts are somewhat between those for the wet and dry periods.

Major rainfall events on W-1 and W-2 (2, 4) show distinctly different time-distribution patterns and depth-area relations for short (less than 12 hours) and long (greater than 12 hours) rains. For most short-duration storms, about 75 percent of total rainfall occurs during the first half of the storm period, whereas only 40 percent of total rainfall occurs during the first half of most long-duration storms.

Curves expressing rainfall depth-area relations for the watersheds indicate greater areal rainfall variability for short-duration storms than for long-duration storms. Average rainfall for a 100-square-mile area is about 52 percent of maximum recorded point rainfall for short-duration storms on both watersheds. For long-duration storms, depth-area relations are different for the coastal (W-1) and inland (W-2) watersheds, with the coastal watershed rainfall showing greater areal variability. For the long-duration storms, average rainfall over a 100-square-mile area is approximately 77 percent of maximum point rainfall for W-1 and 82 percent for W-2.

Annual flood flows resulting from extreme rainfall events on the Vero Beach watersheds were examined by Stephens and Mills (5, 6) and a simplified technique was developed for estimating occurrence probabilities of various 24-hour peak flow rates for different size drainage areas. With this technique, they estimated that a 10-inch rain in 24 hours on a 100-square-mile drainage area with average moisture conditions will produce a peak 24-hour flow rate of 5,500 cubic feet per second. According to U.S. Weather Bureau frequency prediction (1), a rain of this volume and intensity has a 50-year return period for the vicinity of the experimental watersheds. For a 6½-inch rain in 24 hours (5-year return period), a peak 24-hour flow rate of 2,900 c.f.s. is estimated. These flood flow estimates are believed to be applicable to other areas of the southern Florida flatwoods having similar soil moisture storage conditions.

Rainfall and associated streamflow data from selected storm events recorded on Vero Beach subwatershed W-3 were used to test a numerical method for nonlinear storm hydrograph analysis (3). This method, developed at the Southeast Watershed Research Center makes use of two-stage convolution. The first stage convolves a fixed area-characteristic function with a variable state function. The state function is determined by streamflow and differs for each increment of effective rainfall.[3] First-stage convolution thus produces a different unit response for each increment. The second stage convolves the variable unit responses and the effective rain increments to produce a discharge hydrograph.

The two-stage convolution method was incorporated with nonlinear least squares fitting techniques into a computer program, thereby providing for derivation of unit responses and characteristic and state functions from storm rainfall and streamflow data.

Results of the tests using Vero Beach W-3 storm data clearly indicate that this watershed has nonconstant response to effective rainfall. These results also show that using this numerical technique, similar watershed characteristic functions can be derived from rainfall events having widely varying properties.

The two-convolution method was also used for analysis of water yield by 5-day periods. In addition to characteristic and state functions analogous to those in the hydrograph model, the yield model contains a seasonal loss component. All three components are derived simultaneously by the least-squares optimization. Rainfall and runoff data from the W-2 watershed were used to test the yield model. The loss curve derived for W-2 is seen to be a rational expression of the seasonal regimen of precipitation and the storage capacity of the soil profile for central and southern Florida.

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[2] Long-term rainfall averages for W-1 and W-4 are based on a 69-year (1901-69) U.S. Weather Bureau record at Fort Pierce, Fla. Long-term averages for W-2 are based on a 51-year (1919-69) USWB record at Okeechobee Hurricane Gate 6, Florida.

[3] In this report, effective rainfall is that rainfall which produces all categories of runoff.

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(4) Speir, W. H., Mills, W. C., and Stephens, J. C.
1969. Hydrology of three experimental watersheds in southern Florida—a progress report. U.S. Dept. Agr. ARS 41-152, 50 pp.

(5) Stephens, J. C. and Mills, W. C.
1965. Using the Cypress Creek formula to estimate runoff rates in the southern coastal plain and adjacent flatwoods land resource areas. U.S. Dept. Agr. ARS 41-95, 17 pp.

(6) ____________ and Mills, W. C.
1966. Evaluating and applying the Cypress Creek drainage formula. Amer. Soc. Agr. Engin. Trans. 9(4): 550-552, 555.

CHAPTER 3.--TIFTON, GA.

W. C. Mills[1]

Little River experimental watershed near Tifton, Ga., was selected in 1966 for intensive hydrologic investigations. It is located in the Southern Coastal Plain and is considered to be generally representative of upstream agricultural watersheds in a large portion of this land resource area. Demands upon water resources of this region are becoming greater as both agricultural and industrial uses expand. Information to be gained from the Little River hydrologic studies is needed for planning, development, and efficient use of upstream water resources throughout the Coastal Plain. Various phases of the Little River Basin hydrology are monitored to provide data needed for hydrologic analysis. In addition, hydrologic measurements are made on a small adjacent watershed, which is becoming urbanized, to provide for evaluation of urbanization effects on the quantity and quality of streamflow.

Precipitation on the Tifton watersheds and surrounding area is monitored by a network of 55 digital-type rain gages covering a 250-square-mile area. Figure 1 shows the watersheds and location of rain gages. Table 1 gives details on elevation and dates of operation for the gages.

A major objective in observing and analyzing precipitation on the Tifton experimental watersheds is to evaluate properties of precipitation input as a necessary first step in determining effects of these properties on other phases of the basin hydrology.

Another important objective is to characterize consistent patterns of rainfall distribution in time and space, thereby providing information for estimating precipitation patterns for other watersheds in the region.

TOPOGRAPHY

Topography of the Tifton watersheds is slightly rolling. Elevations range from approximately 270 feet above sea level in the Little River flood plain at the downstream end of the experimental area to about 460 feet on the upper ridges of the basin. This is typical of topographic conditions throughout the Southern Coastal Plain. The Atlantic Coast Flatwoods Land Resource Area, which has a more nearly level terrain, begins about 15 miles southeast of Tifton and extends to the Atlantic Ocean. The Gulf Coast Flatwoods with similar terrain is situated about 60 miles to the south. The experimental watersheds are approximately 120 miles from the Atlantic Ocean and 90 miles from the Gulf of Mexico. About 70 miles north of the watersheds, the Sand Hills separate the gently rolling slopes of the Coastal Plain from the steeper slopes of the Piedmont. The nearest mountain range is 180 miles north-northwest of the Tifton rain gage network.

PROCESSING STATUS OF DATA

Precipitation caught by gages in the Tifton network is automatically recorded at 5-minute intervals in digital form on four-channel paper tape. Amounts are recorded to the nearest tenth of an inch, and a code is punched to indicate rainfall trace. The punched tape is periodically (usually monthly) removed from the gage recorders and visually edited to detect any obvious errors. The precipitation data are then machine translated from paper tape to cards for computer input. Cards containing precipitation records of all gages for a month constitute an input file for a preprocessing computer program. This program changes the form of the precipitation data from cumulative amounts as recorded to 5-minute rainfall, increments, while retaining rain-trace codes. The program also checks for rainfall amounts erroneously recorded when no rain occurred. Errors detected during this check are manually corrected on the input cards and the preprocessing program is run again using the corrected input file. This step is

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[1] Research hydraulic engineer, Southeast Watershed Research Center, P. O. Box 469, Athens, Ga. 30601.

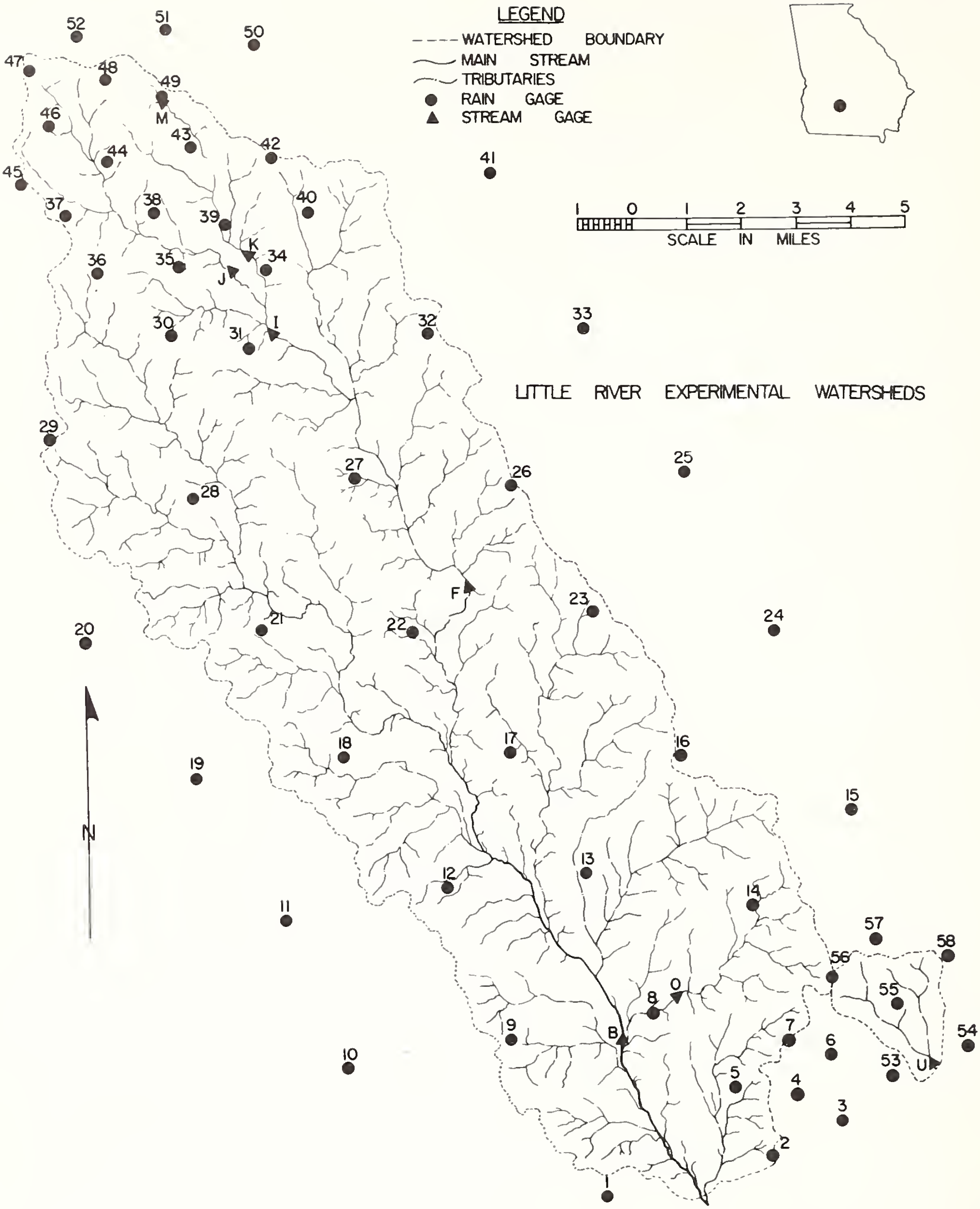

Figure 1.–Rain gage network on Tifton, Ga., experimental watersheds.

repeated until no errors are detected by the program. The output file from the preprocessing program contains 5-minute incremental rainfall and rain-trace codes for each gage for a month. This monthly file is temporarily stored on a magnetic tape.

A second computer program uses the monthly precipitation files as input and progressively builds an annual precipitation file. During this step, daily rainfall for each gage is computed and summed to obtain monthly totals. A frequency distribution of arithmetically averaged daily rainfalls for the network is prepared both for occurrences during the month and for occurrences from the beginning of the year. Tables are printed showing the daily and

Table 1.–Details of rain gage network on Tifton, Ga., experimental watersheds

Gage No.[1]	Elevation above mean sea level	Record began	Record terminated[2]
	Feet	*Date*	*Date*
1	380	1-24-67	
2	345	3-2-67	
3	370	2-23-67	
4	340	3-2-67	6-5-69
5	335	3-2-67	6-6-69
6	390	3-3-67	
7	375	3-3-67	6-3-69
8	280	3-3-67	
9	360	3-8-67	
10	300	1-24-67	
11	300	3-13-67	
12	360	3-13-67	
13	350	1-23-67	
14	350	3-14-67	
15	420	2-23-67	
16	450	4-17-67	
17	360	3-13-67	
18	350	1-23-67	
19	340	3-16-67	
20	375	1-23-67	
21	375	3-13-67	
22	320	1-20-67	
23	350	3-14-67	
24	425	3-14-67	
25	400	1-20-67	
26	360	3-14-67	
27	340	1-20-67	
28	410	4-26-67	
29	410	1-17-67	
30	420	1-18-67	
31	410	1-18-67	
32	380	3-15-67	
33	380	1-20-67	
34	340	1-19-67	
35	420	2-24-67	
36	430	1-19-67	
37	450	1-16-67	
38	460	1-17-67	
39	350	2-20-67	
40	360	1-19-67	
41	380	1-17-67	
42	440	1-18-67	
43	380	1-17-67	
44	430	1-12-67	
45	410	1-12-67	
46	410	1-19-67	
47	410	1-12-67	
48	460	1-11-67	
49	390	1-11-67	
50	430	1-9-67	
51	450	1-11-67	
52	460	1-11-67	
53	380	8-7-69	
54	375	8-7-69	
55	390	6-6-69	
56	400	6-5-69	
57	420	7-11-69	
58	420	8-8-69	

[1] All gages are digital recording type.

[2] Record is continuing if no date of termination is shown.

monthly rainfall amounts and frequency distributions. The annual precipitation file, which is stored on magnetic tape, contains this summary information in addition to the 5-minute rainfall increments and trace codes.

PRECIPITATION CLIMATOLOGY

Precipitation in the Tifton, Ga., area occurs almost exclusively as rainfall. Average annual rainfall for a 47-year record at the Coastal Plains Experiment Station at Tifton is 47.10 inches. According to long-term monthly averages at this station, there is a very pronounced maximum and minimum in the seasonal rainfall distribution. Maximum rain occurs in midsummer and minimum in autumn. The average rainfall for July is more than three times that for either October or November. A second maximum in the annual rainfall curve occurs in March and a second minimum in May; however, these are not nearly as pronounced as the summer and autumn extremes.

For individual years, annual rainfall and seasonal distribution has varied widely from the long-term averages. Annual rainfall was only about 38 inches and seasonal distribution was sporadic for the first 2 years (1967-68) of operation for the Tifton rain gage network.

Individual summer rains are usually associated with thunderstorm activity, and the areal distribution is highly variable. For 15 major summer rains occurring in 1967 and 1968, average rainfall over the Tifton network ranged from 16 to 50 percent of maximum recorded point rainfall.

Floods in the Little River Basin resulting from extreme rainfall events are depicted by an annual flood frequency curve derived from annual flood peaks recorded on Little River since 1951. This curve shows a 50-year return period for a peak discharge of 9,000 c.f.s. from a 145-square-mile drainage area. The mean-annual flood (2.33-year return period) for this drainage area is about 1,600 c.f.s.

CHAPTER 4.--REYNOLDS CREEK, IDAHO

W. Russell Hamon[1]

The Northwest Watershed Research Center operates a dense precipitation gage network as an integral part of the hydrologic studies[2] in the Reynolds Creek Experimental Watershed located in southwestern Idaho. Overall, the research mission of the study is to gain a better understanding of the role of the land and the influences of vegetation, climate, and land management on the movement of water and sediment. Accurate point measurements of precipitation at sufficient sites to determine the temporal and spatial variations in precipitation are needed to develop a predictive hydrologic model.

The Reynolds Creek Experimental Watershed, a rugged 90-square-mile area in the Owyhee Mountains, forms the headwaters of a north-flowing tributary of the Snake River (fig. 1). The lowest elevation is about 3,600 feet. The eastern watershed boundary rises to about 5,000 feet; the western, to 6,000 feet; and the southern, to a peak of 7,200 feet. Isolated peaks a few miles south and west reach elevations of 8,000 feet. Prevailing winds and most precipitation are from the southwest. Convective storms during the summer move in a less systematic fashion.

PRECIPITATION GAGE NETWORKS

The present network of precipitation gages (fig. 1)[3] consists of dual-gage installations with one shielded and one unshielded recording gage at each site. The original unshielded recording gage network (fig. 2), installed in 1960-61, was replaced by the dual-gage network in 1967-68. A typical dual-gage site is shown in figure 3. An evaluation site, established to study precipitation gage performance is shown in figure 4. Unshielded gage installations are shown in figures 5 and 6. In figure 6, the gage orifice is elevated to about 10 feet to prevent inundation by snow.

Unshielded Gage Network

The unshielded gage network, essentially consisting of one recording precipitation gage per square mile, was in operation in the Reynolds Creek Experimental Watershed for the period 1961-67. Gage location, orifice height, elevation of gage, and period of operation are given in table 1. During the snow season data from this network will require adjustment before use because any precipitation gage exposed to wind is known to catch something less than the actual precipitation. A windshield is beneficial in reducing the wind effect but only partially corrects the situation. The alternative of placing gages in sheltered locations is not realizable because of the sparsely vegetated, exposed terrain in the watershed (figs. 3, 5, and 6).

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[1] Research hydraulic engineer, Northwest Watershed Research Center, P. O. Box 2700, Boise, Idaho 83701.

[2] Robins, J. S., Kelly, L. L., and Hamon, W. R. Reynolds Creek in southwest Idaho: an outdoor hydrologic laboratory. Water Resources Res. 1(3):407-413. 1965.

[3] Gage locations shown in figure 1 are found by use of the Federal system of land division with each section numbered as shown from the upper left (northwest) corner in rows of 10. Each section is subdivided into 100 squares, as indicated in the subdivided section in the upper right corner of the map. Within a numbered section, a location is found by moving down any section to the row, and then across to the proper column. A precipitation site is designated by a six-digit number. The first three digits represent the section, and the last two digits represent the location of the smallest subdivision within the section. The fourth digit is used as a code to note the type of gage or other precipitation measuring device.

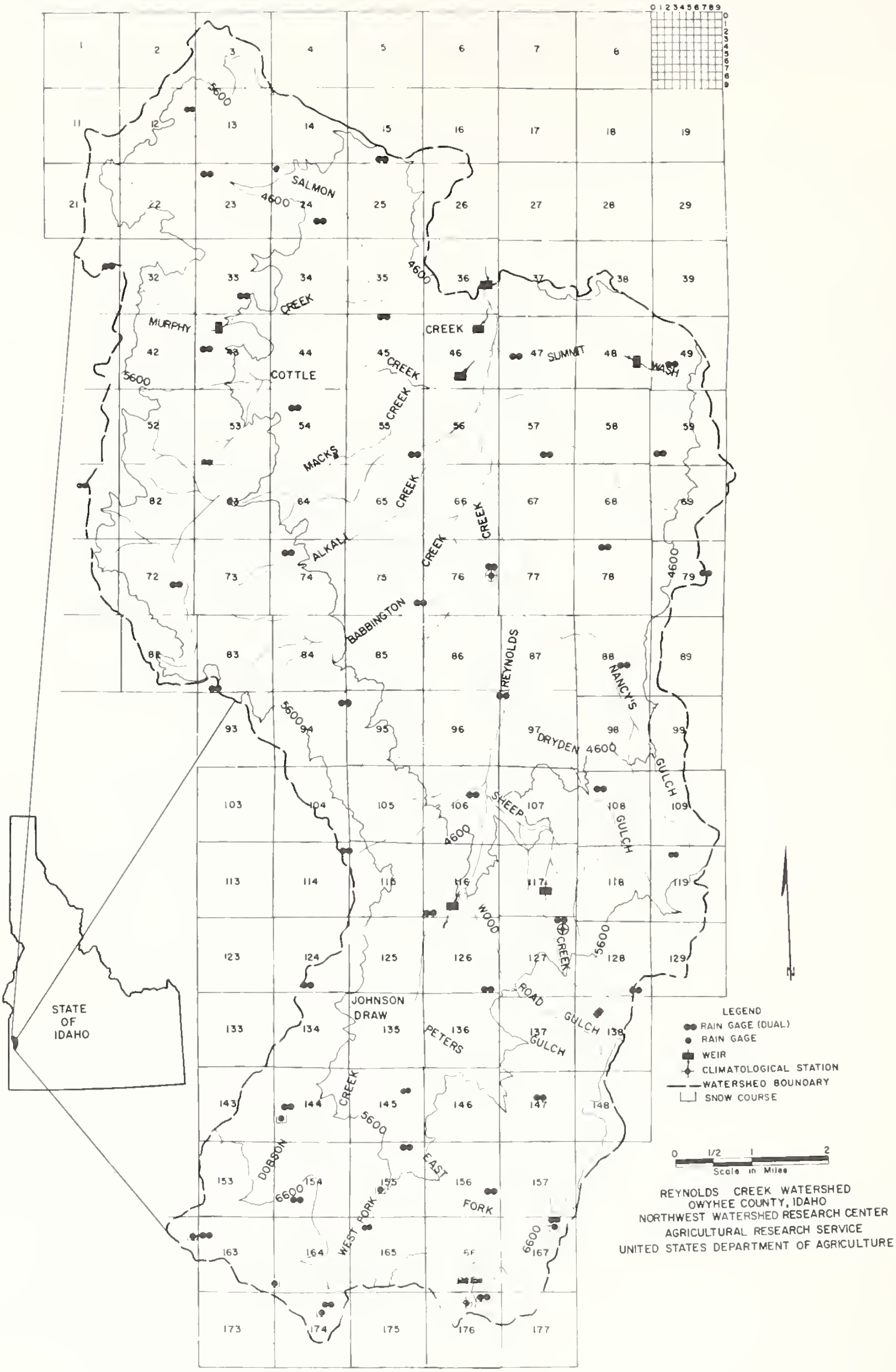

Figure 1.—Topographic and rain gage network, Reynolds Creek, Idaho. (See text footnote 12 for system of numbering gages.)

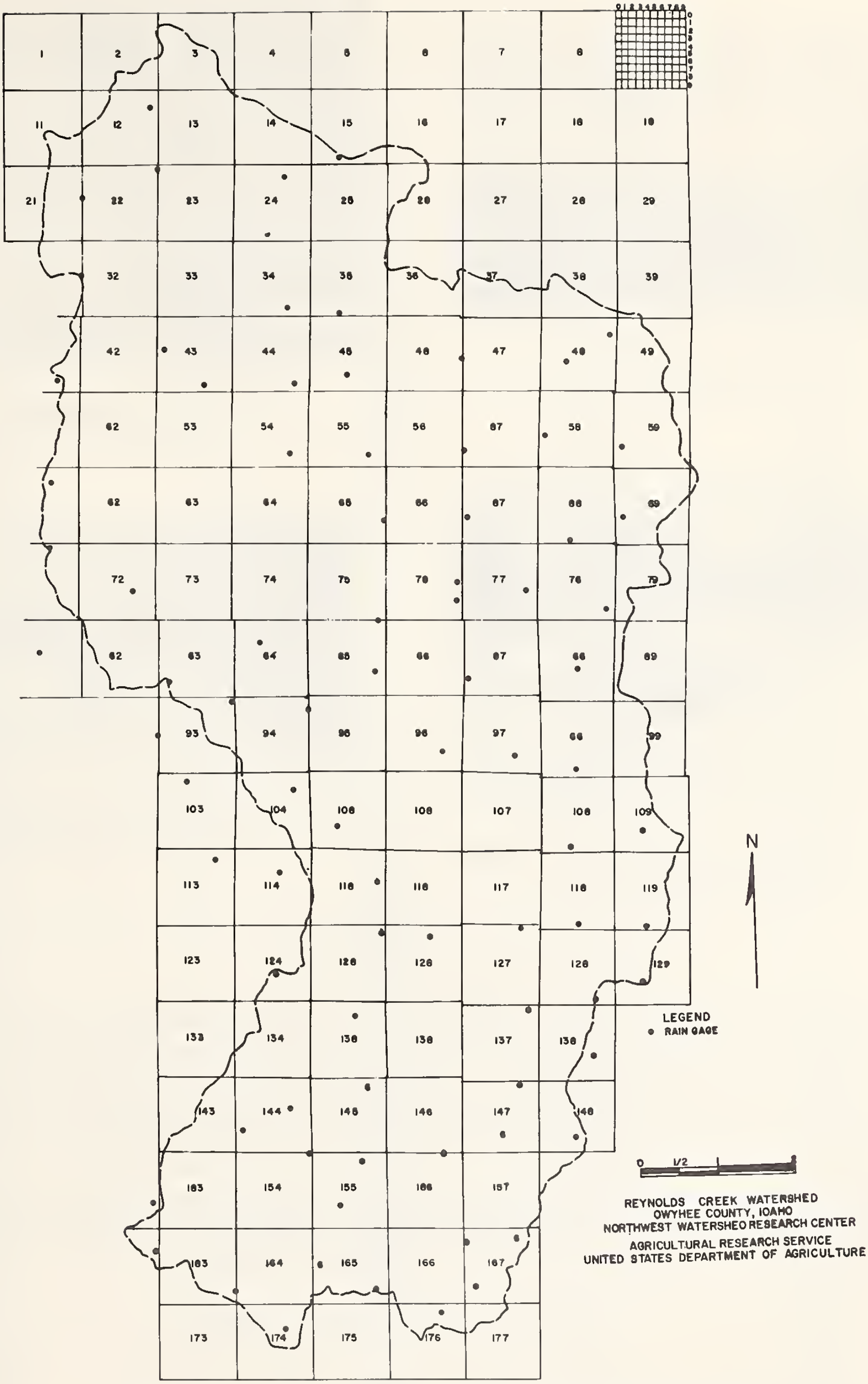
N
LEGEND
● RAIN GAGE
0 1/2 1
REYNOLDS CREEK WATERSHED
OWYHEE COUNTY, IDAHO
NORTHWEST WATERSHED RESEARCH CENTER
AGRICULTURAL RESEARCH SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

Figure 2.—Unshielded recording gage network, Reynolds Creek, Idaho.

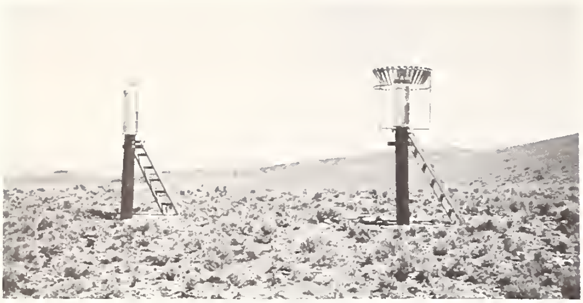

Figure 3.–Typical recording precipitation gage installation in dual-gage network.

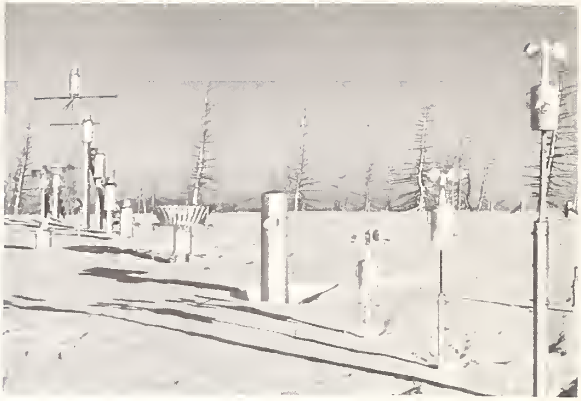

Figure 4.–Precipitation gage evaluation site (Reynolds Mountain).

Figure 5.–Typical unshielded recording precipitation gage installation at *lower* elevations.

Figure 6.–Typical unshielded recording precipitation gage installation at *higher* elevations.

Dual-Gage Network

Investigations into methods of obtaining adequate precipitation data, particularly where the precipitation is principally snowfall, were initiated in 1964. The dual-gage installation–one gage unshielded and one gage shielded–was found to give the data required to compute "actual" precipitation. These research findings were presented in a paper, "Measurement of Atmospheric and Ground-Level Precipitation," at the 50th Annual Meeting, American Geophysical Union, San Francisco, December 15-18, 1969, and is scheduled for publication in the Transactions.

Procedures for computing "actual" precipitation were developed from the basic equations relating the ratios U/A and S/A to windspeed, where U and S represent catches by unshielded and shielded gages, respectively, and A represents the vertical flux of precipitation. These basic equations take the form

$$\text{(1a)}\ \frac{S}{A} = e^{-aW}; \qquad \text{(1b)}\ \frac{U}{A} = e^{-bW} \tag{1}$$

which may be combined to obtain

$$\frac{U}{S} = e^{-(b-a)W} \tag{2}$$

Table 1.–Unshielded gage network in Reynolds Creek watershed[1]

Gage No.	Orifice height	Elevation of gage	Date installed	Date removed
	Feet	*Feet*		
012029[2]	5	5,180	10/4/60	12/21/67
022040	5	5,400	9/13/60	12/8/67
023000	5	4,875	9/13/60	12/8/67
024017	5	4,475	8/1/61	8/4/67
015094	5	4,540	9/13/60	1/16/68
032030	5	5,960	10/4/60	8/4/67
024095	5	4,440	8/2/61	1/16/68
041088	5	5,950	8/22/61	12/8/67
043041	5	4,760	8/10/60	12/21/67
034078	5	4,130	8/9/60	8/4/67
035094	5	3,975	10/4/60	1/3/68
061016	5	5,840	8/21/61	12/7/67
043097	5	4,395	8/10/60	12/21/67
044098	5	4,045	8/30/60	1/23/68
045086	5	3,850	8/10/60	8/4/67
047060	5	3,710	7/1/60	1/18/68
048064	5	3,970	7/25/60	8/4/67
048029	5	4,145	7/1/60	3/6/68
071006	5	5,670	8/2/61	12/7/67
054088	5	4,080	8/10/60	1/24/68
055088	5	3,825	8/10/60	1/22/68
057081	5	3,790	7/25/60	11/8/68
058050	5	3,985	7/25/60	3/6/68
059071	5	4,355	8/1/61	1/19/68
072067	5	5,260	10/5/60	11/22/67
066070	5	3,960	8/10/60	2/20/68
067061	5	3,900	7/20/60	9/9/67
068094	5	4,260	8/1/61	8/9/67
069061	5	4,460	8/1/61	1/22/68
081045	5	5,537	8/16/61	8/30/67
083081	5	5,620	10/5/60	8/9/67
084034	5	4,800	10/5/60	2/20/67
085009	5	3,960	7/1/60	1/18/68
076079	5	3,965	7/1/60	8/9/67
076059	5	3,925	3/31/65	Operating
077068	4.5	4,060	8/11/60	8/9/67
078088	5	4,440	7/5/60	8/9/67
093040	5	5,475	8/16/61	12/7/67
094010	5	5,550	7/20/60	8/9/67
095020	5	4,875	7/20/60	12/20/67
085069	5	4,125	8/11/60	8/9/67
087071	5	4,040	8/11/60	11/19/67
088065	5	4,348	7/28/60	12/29/67
103014	5	5,688	8/16/61	8/30/67
104028	5	5,535	8/11/61	11/20/67
105073	5	5,325	8/17/61	8/30/67
096077	5	4,210	7/20/60	1/19/68
097076	5	4,375	9/12/61	8/30/67
098085	5	4,638	9/31/61	12/27/67
113017	5	5,545	8/16/61	8/30/67
114036	5	5,762	10/5/60	8/30/67
115049	5	5,120	8/17/61	8/15/67
108094	5	5,200	7/28/60	8/24/67
109074	5	5,065	9/13/61	2/14/68
124065	5	5,873	8/16/61	11/20/67
125009	5	4,760	7/5/60	1/18/68
126016	5	4,875	9/12/61	9/18/67
127007	5	5,420	11/5/65	Operating
118094	5	5,720	7/28/60	8/24/67
119094	5	5,650	9/13/61	3/7/68
135016	5	4,860	7/25/60	1/18/68
137008	5	6,050	7/28/60	3/22/68
128097	5	6,655	12/14/61	3/7/68

See footnotes at end of table.

Table 1.–Unshielded gage network in Reynolds Creek watershed–Continued

Gage No.	Orifice height	Elevation of gage	Date installed	Date removed
	Feet	*Feet*		
144061	10	5,940	9/6/61	Operating[3]
144047	5	5,620	8/17/61	11/17/67
145017	5	5,225	8/17/61	1/17/68
147007	5	6,185	7/28/60	8/24/67
138076	5	6,500	9/31/61	8/24/67
152069	10	6,940	9/6/61	9/18/67
155000	5	5,920	7/29/60	9/18/67
155073	10	5,715	8/30/61	Operating[3]
155016	5	5,430	7/25/60	1/17/68
156007	5	6,215	9/12/61	8/24/67
147075	5	6,015	9/12/61	3/22/68
148074	5	6,720	9/12/61	1/10/67
162029	10	7,175	9/5/61	Operating[3]
163089	10	6,985	9/5/61	Do.
165040	10	6,220	8/3/61	7/1/68
167010	5	6,240	7/25/60	1/11/68
167017	10	6,680	8/31/61	3/22/68
174036	11	6,820	9/5/61	Operating[3]
165088	10	6,740	7/28/60	8/15/67
167071	5	6,610	7/28/60	8/24/67
176007	10	6,800	9/1/61	1/30/68

[1] U.S. Weather Bureau standard recording gage with 8-inch orifice. (Data as of Jan. 1, 1970.)

[2] For gage locations in figure 7, see text footnote 3.

[3] Data obtained only during winter since July 1968.

where a and b are constants and W is the windspeed. When wind is eliminated by simultaneous solution of equations 1 and 2, a calibration equation is obtained in the form

$$\ln\left(\frac{U}{A}\right) = B \ln\left(\frac{U}{S}\right) \qquad (3)$$

The calibration constant, B, has been evaluated as approximately 1.73 from profile measurements of unshielded precipitation gage catch and wind (fig. 4). Also, data from a snow pillow site along with catches by shielded and unshielded gages were used to substantiate the profile computations.

Information on the dual-gage network, including elevations of the sites and dates established, is listed in table 2.

STATUS OF DATA

Breakpoint data from all gages listed in tables 1 and 2 have been transferred to punchcards. Error programs are yet to be run, and estimates to complete a number of records have not been made. A reduction program to compute actual precipitation using data from the dual precipitation gage network has been written. Procedures for adjusting the data obtained from the unshielded gage network are to be worked out, and computer programs will be written in the near future.

ANALYSIS OF DATA

Unshielded Network

An analysis has been made of the relationship between rainfall intensity and elevation[4] using 4 years of data from the unshielded network for the spring and summer months. Rainfall bursts amounting to 0.10 inch or more

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[4] Cooper, C. F. Rainfall intensity and elevation in southwestern Idaho. Water Resources Res. 3: 131-137. 1967.

Table 2.—Dual-gage network in Reynolds Creek watershed[1]

Gage No.[2]	Elevation of gages	Date installed	Gage No.	Elevation of gages	Date installed
	Feet			*Feet*	
012429	5,180	12/21/67	088465	4,410	12/29/67
012529[3]	–	12/21/67	088565	–	2/7/68
015495	4,520	2/7/68	095410	4,880	12/20/67
015595	–	1/23/68	095510	–	12/20/67
023401	4,880	12/8/67	097400	4,080	1/22/68
023501	–	12/8/67	097500	–	1/22/68
024476	4,435	2/7/68	106436	4,270	1/18/68
024576	–	1/16/68	106536	–	1/18/68
031448	5,875	12/8/67	108404	4,810	1/2/68
031548	–	12/8/67	108504	–	12/27/67
033476	4,660	1/24/68	114419	5,885	11/20/67
033576	–	1/23/68	114519	–	11/20/67
043441	4,795	12/21/67	116491	4,770	1/18/68
043541	–	12/21/67	116591	–	1/18/68
045404	4,000	1/3/68	119403	5,490	3/7/68
045504	–	2/7/68	119503	–	3/7/68
047452	3,710	1/22/68	124484	5,920	11/20/67
047552	–	3/8/68	124584	–	11/20/67
049461	4,280	1/29/68	126497	5,460	3/22/68
049561	–	3/8/68	126597	–	3/22/68
053493	4,950	12/21/67	127407	5,410	2/13/68
053593	–	12/21/67	127507	–	2/13/68
054423	4,430	1/25/68	128487	6,540	3/7/68
054523	–	1/25/68	128587	–	3/7/68
055488	3,820	1/2/68	144462	5,930	11/17/67
055588	–	2/29/68	144562	–	11/17/67
057496	3,885	1/29/68	145437	5,195	1/18/68
057596	–	3/4/68	145537	–	1/17/68
059481	4,390	3/6/68	147435	6,140	3/22/68
059581	–	1/22/68	147535	–	3/22/68
061425	5,880	12/7/67	154464	6,860	11/2/67
061525	–	12/7/67	154564	–	11/2/67
072467	5,235	11/22/67	155407	5,410	1/18/68
072567	–	11/22/67	155507	–	1/17/68
074412	4,720	2/29/68	156468	6,320	11/17/67
074512	–	2/29/68	156568	–	11/17/67
075489	3,950	1/22/68	163420	7,100	10/26/67
075589	–	3/8/68	163520	–	10/26/67
076459	3,915	12/29/67	165402	5,950	12/3/69
076559	–	1/22/68	165502	–	1/13/70
078414	4,270	3/6/68	167407	6,600	3/22/68
078514	–	1/12/67	167507	–	3/22/68
079447	4,920	4/4/68	174417	6,760	11/8/68
079547	–	4/4/68	174517	–	11/8/68
083492	5,510	11/22/67	176407	6,800	10/23/67
083592	–	11/22/67	176507	–	10/26/67

[1] Each site is instrumented with two U.S. Weather Bureau standard recording gages located 20 feet apart. Orifices are 8 inches in diameter and 10 feet above ground. One gage is equipped with a modified Alter shield with leaves individually constrained at an angle of 33° from the vertical. Top of shield is at height of gage orifice and bottom of leaves extend toward gage. (Data as of Jan. 1, 1970.)

[2] For system of numbering gage locations shown in figure 1, see text footnote 3.

[3] Gage with shield contains a number 5 as fourth digit in gage number.

were considered. The maximum amount recorded was 0.49 inch falling at a rate of 9.8 inches per hour for 3 minutes. Rainfall in excess of 0.8 inch per hour occurred an average of once a year. Almost all intense storms during the period of study began between 1600 and 2200 hours local time. The logarithm of the amount of rain falling in excess of a given intensity plotted as a straight line against elevation with no significant departure in this relationship when the data were separated into elevation zones. It was also found that the amount of rainfall decreased by about one-half with each 1-inch-per-hour increase in rainfall rate. These findings suggest that data from accessible valley stations can be used to estimate the relative frequency of high intensity rains throughout an area of appreciable range in elevation.

Attempts to establish definitive precipitation-elevation relationships for other than strictly rainfall data have been unsuccessful when using unshielded gage data. The weak correlations obtained are attributable to the inability of the unshielded gage to capture the falling precipitation, particularly snow, when exposed to even light winds.

Dual-Gage Network

Data from the dual-gage network have been used to compute actual precipitation by use of equation 3. Some preliminary analyses have been made to examine the precipitation-elevation relationship using the computed values.

Precipitation values computed with equation 3 are essentially uninfluenced by wind or type of precipitation. The constants in equations 1 and 2 are greatly different for rain and snow, and the ratio of unshielded to shielded catch, or, better, the ratio of unshielded catch to computed actual precipitation, can be used to determine the occurrence of rain or snow at exposed, windy sites.

The ratios of monthly unshielded to shielded catch for a 12-month period from 10 dual-gage sites are shown in table 3. Because the ratio is about 0.90 for rainfall with a wind of 25 miles per hour, it can be assumed that the precipitation at a location is essentially snowfall for those months where the ratio is less than 0.90. Precipitation, therefore, occurs predominantly as snow at an elevation of about 4,000 feet from December through April, and at 7,000 feet, the snow season extends from September into May (table 3). On this basis, the 1 year of computed precipitation indicates that about 45 percent of the precipitation occurs as snow at 4,000 feet and about 80 percent, as snow at 7,000 feet elevation. A better assessment must await the analyses of data on a storm basis, as significant rainstorms do occur during the winter months.

Precipitation values were computed for a 24-hour duration storm, beginning on November 11, 1969. The air temperature at an elevation of 6,800 feet was 30° F. during the storm. The precipitation-elevation relationship, found by use of computed precipitation values for the curve shown in figure 7 is represented by the regression equation

$$Y = 0.2735X - 0.6865 \qquad (4)$$
$$(r = 0.98)$$

Table 3.–Ratio of monthly unshielded to shielded catch for July 1968 through June 1969

Station	Elevation	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
	Feet												
057X96	3,885	–	0.97	1.00	0.95	0.91	0.87	0.93	0.81	0.83	0.82	1.00	0.95
075X89	3,950	–	.99	1.00	.97	.94	.87	.87	.86	.86	.88	.96	1.00
106X36	4,270	1.00	.98	1.00	.94	.93	.85	.92	.63	.84	.80	1.00	.98
043X41	4,580	1.00	.99	.94	.87	.82	.77	.87	.67	.74	.80	.85	.97
116X91	4,770	1.00	.97	.90	.91	.90	.83	.88	.67	.82	.77	.96	.95
145X37	5,195	1.00	1.00	.96	.95	.92	.90	.92	.76	.73	.76	1.03	.99
031X48	5,880	1.00	.96	.90	.92	.80	.63	.60	.60	.47	.64	.92	.95
144X62	5,930	.96	.95	.85	.91	.90	.85	.89	.73	.73	.71	.86	.91
176X07	6,800	–	.98	.89	.87	.87	.77	.78	.59	.63	.67	.95	.95
163X20	7,100	1.00	.96	.82	.83	.82	.77	.81	.74	.46	.71	.91	.94

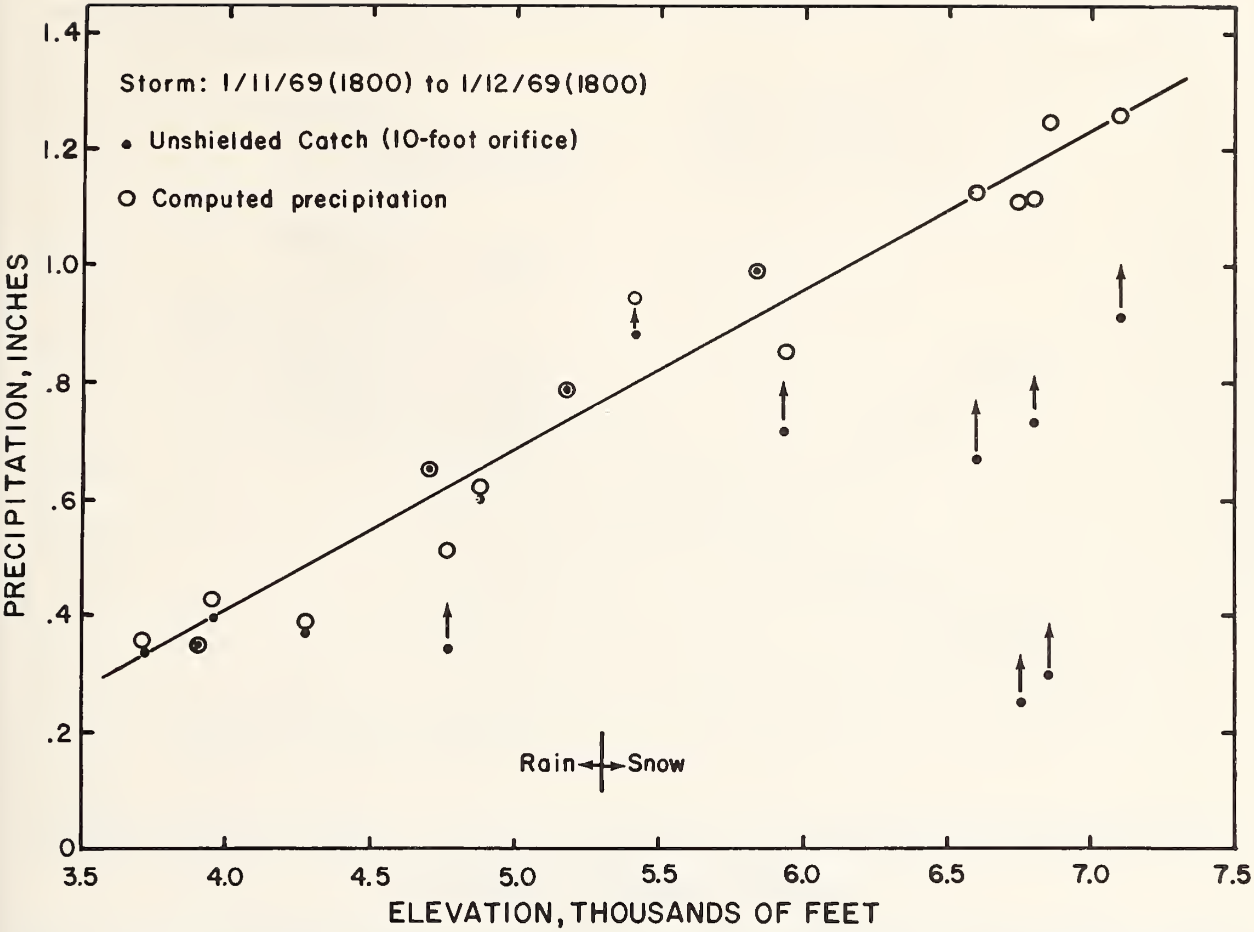

Figure 7.–Precipitation-elevation relationship for computed storm totals in the Reynolds Creek watershed, Owyhee County, Idaho.

where Y is the computed precipitation in inches, X is the elevation in thousands of feet, and r is the simple correlation coefficient. The ratios of unshielded catch to computed precipitation indicate that snow fell at elevations above 5,300 feet. The ratio of unshielded catch to computed precipitation was only 0.23 at a ridge site (station 174X17 at 6,760 feet elevation).

The precipitation-elevation curves obtained from monthly totals for unshielded and shielded gages, and computed precipitation accumulated over a period of 1 year are shown in figure 8.

The regression equations are as follows with definitions the same as for equation 4:

$$\text{(Unshielded)} \quad Y = 6.34X - 12.46 \quad (r = 0.89) \tag{5}$$

$$\text{(Shielded)} \quad Y = 8.43X - 20.09 \quad (r = 0.93) \tag{6}$$

and

$$\text{(Computed)} \quad Y = 10.45X - 27.60 \quad (r = 0.95) \tag{7}$$

Use of monthly data rather than storm data in equation 3 may introduce a slight bias because the calibration coefficient was obtained from storm data and because of the nonlinear relationship.

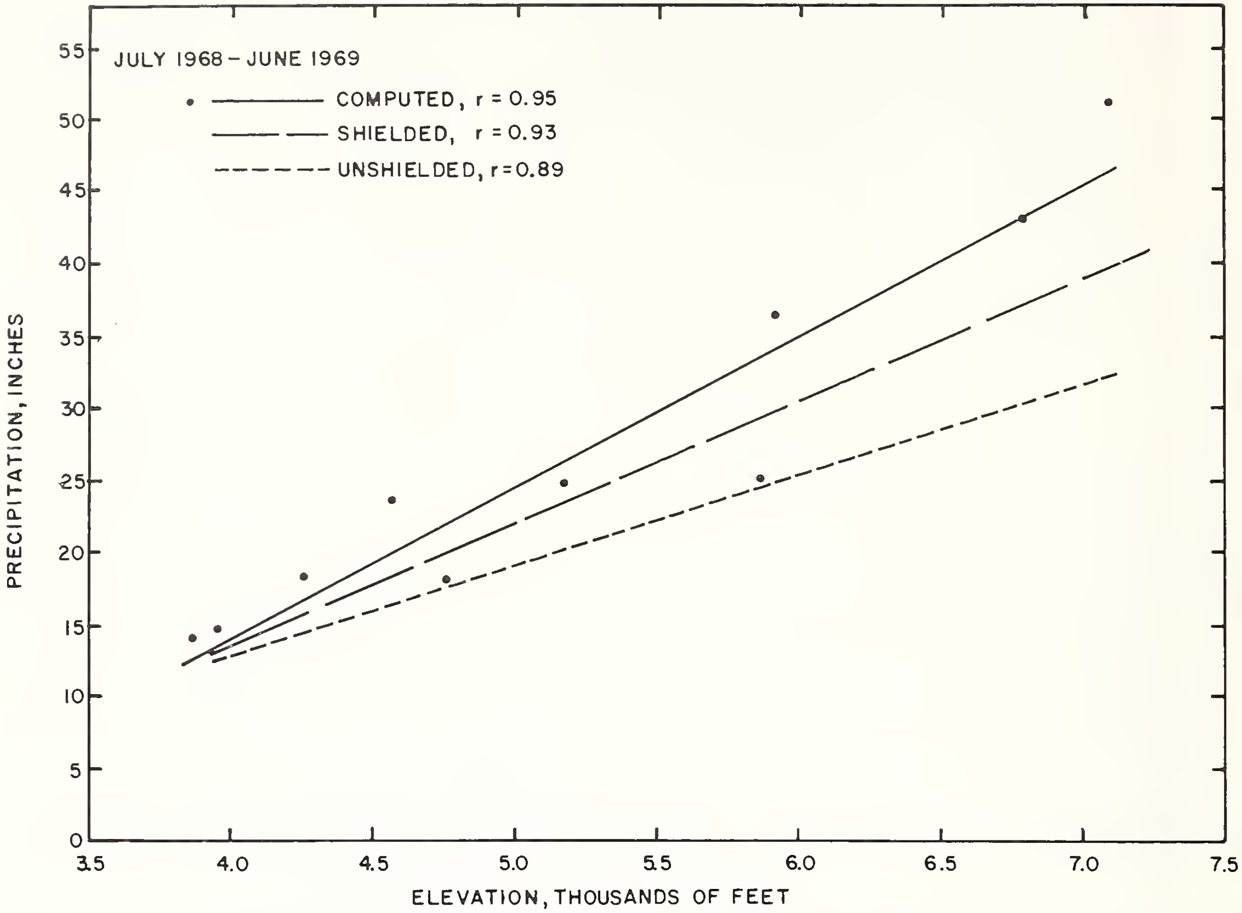

Figure 8.–Precipitation-elevation curves from monthly totals for unshielded and shielded gages, and computed precipitation accumulated over a 1-year period in the Reynolds Creek watershed, Owyhee County, Idaho.

As might be expected, the highest correlation between precipitation and elevation is for the computed precipitation. The increase in shielded catch over unshielded catch is about 23 percent, and the computed values are increased by about 43 percent over the unshielded catch. The rigid shield, in effect, only corrects for less than 50 percent of the wind effect on the unshielded gage catch.

During the winter, precipitation occurs principally as a result of the moist southwestern air current which is lifted by mountainous terrain and by frontal systems. Air mass convective storms, however, are the principal sources of summertime precipitation. Comparisons of the precipitation-elevation relationship for these two seasons are shown in figure 9. On the basis of 1 year of computed precipitation, the regression equation for the November to April period is

$$Y = 8.69X - 26.75 \quad (r = 0.94) \tag{8}$$

and for the May to October period, the regression equation for computed precipitation is

$$Y = 1.70X - 0.87 \quad (r = 0.92) \tag{9}$$

and for unshielded catch, the regression equation is

$$Y = 1.38X + 0.52 \quad (r = 0.39) \tag{10}$$

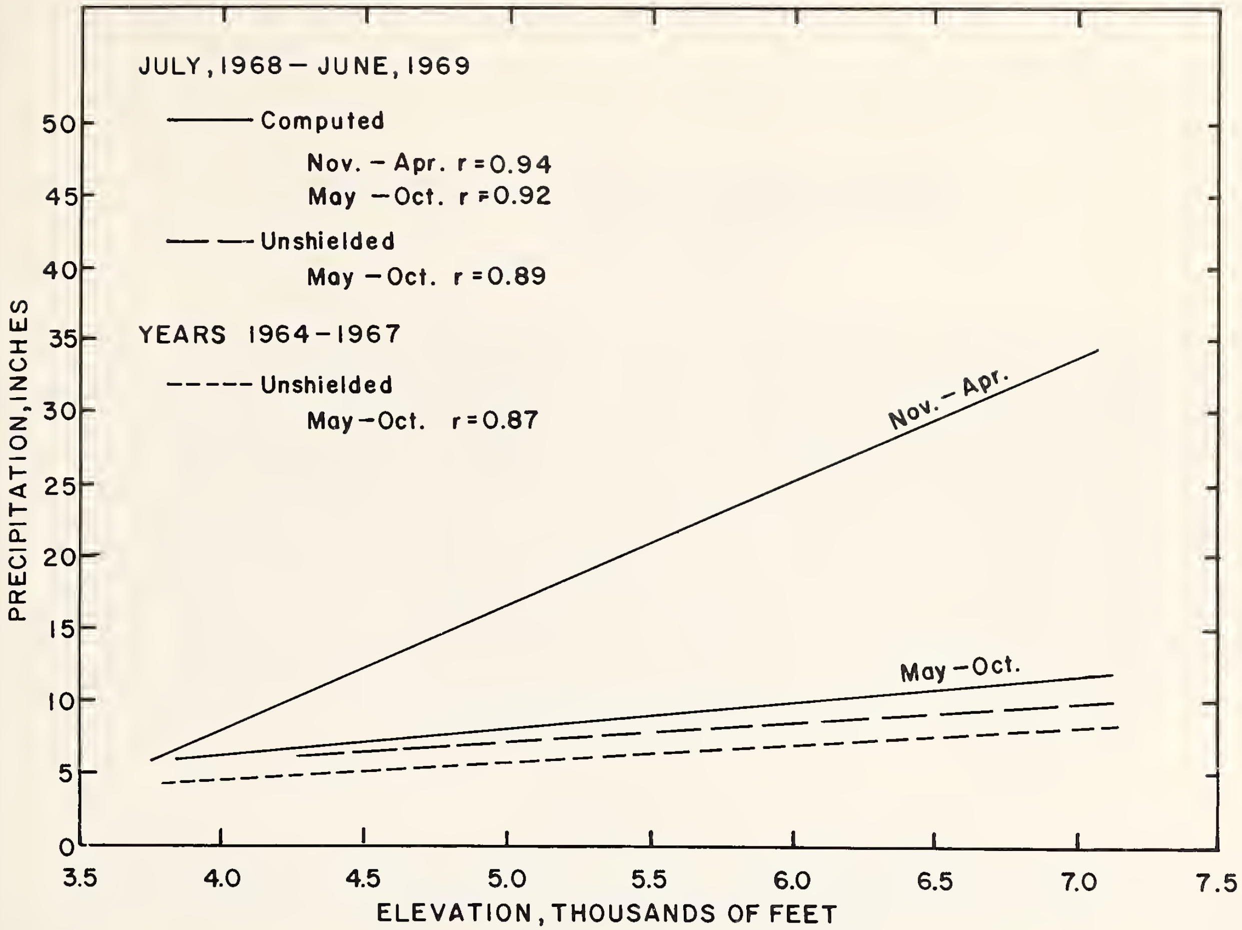

Figure 9.—Seasonal precipitation-elevation relationship for computed precipitation and unshielded gage catch in the Reynolds Creek watershed, Owyhee County, Idaho.

(As stated for equation 4, Y is the precipitation in inches, X is the elevation in thousands of feet, and r is the simple correlation coefficient.)

For comparison with a longer period, the precipitation-elevation relationship for unshielded gage catch over a 4-year period for May to October is represented by the regression equation

$$Y = 1.38X - 1.09 \quad (r = 0.87) \tag{11}$$

It is significant that the slopes of the regression lines are identical for the 1- and 4-year periods. Because of this fact, the computed precipitation-elevation relationships for November to April (equation 8) and for May to October (equation 9) may be considered as representative if we bear in mind that the data used are from stations in the western and southern portions of the watershed. During the November to April period, precipitation increased 8.69 inches (equation 8) with each 1,000-foot rise in elevation, while during the May to October period, this increase was only 1.76 inches (equation 9).

CHAPTER 5.-TREYNOR, IOWA

R. G. Spomer and K. E. Saxton[1]

The rain gage network is located on five experimental watersheds in the deep loess soils area in western Iowa, where gully erosion is a severe problem. Each watershed contains an active gully that is being studied to determine its rate of growth and the volume of soils voided. The processes that cause gully growth, such as surface runoff, ground water seepage, and physical soil behavior, are being identified and their relative importance evaluated. The effect of land use above these gullies is being evaluated by maintaining two watersheds (75 and 83 acres) in contour corn, one (107 acres) in grass cover, one (150 acres) in level-terraced corn, and one (389 acres) in level-terraced mixed crops.

Complementary objectives include hydrologic studies of surface and sub-surface flows. Hydrologic boundaries are well defined for both the surface water and ground water, and all variables within the hydrologic budget are being measured. Soil erosion from the watershed surfaces is calculated from suspended sediment samples of the surface runoff. These erosion rates, which do not include gully erosion, are being related to the land use. Soil and water pollution by commercial fertilizer is being studied by applying two rates of nitrogen and phosphorus on the watersheds. Nutrient levels of the crops, soil, ground water, sediment, and streamflow are being measured.

TOPOGRAPHY

The area topography is that of the rolling midwestern plains. The loess deposition and subsequent erosion have resulted in a well-developed local topography of the watersheds. Surface slopes in the narrow valleys and on the ridges are 2 to 4 percent, whereas those on the sidehills are 10 to 16 percent. Mean sea level elevation ranges from about 1,140 feet in these upland valleys to about 1,240 feet on the ridges. Most valleys have an incised channel which ends upslope in an active gully head. Most of the land is farmed, even though the steep slopes and unstable soil contribute to frequent, severe erosion.

RAIN GAGE LOCATIONS AND DATA

Sixteen recording rain gages are located in three sets to measure the precipitation on the five experimental watersheds. The watershed locations are shown in figure 1, and the individual rain gage locations are shown on more detailed watershed maps in figures 2, 3, and 4. Watersheds 1 and 2 are 2 miles south, and watershed 5 is 10 miles east of watersheds 3 and 4. About 35 plastic, wedge-type rain gages are located on farms in the area surrounding and between watersheds 1, 2, 3, and 4. Total rainfall amounts are obtained from these gages for selected large events.

Details for each of the 16 recording rain gages and their records are given in table 1. All recorder charts are edited soon after field removal, and daily precipitation amounts are determined for each gage. The time distribution of all rainfall recorded by eight gages is tabulated in detail by time-volume readings such that the actual distribution is represented by a series of straight lines. These time-volume values are used as input to a computer program that provides outputs of the recorded times and accumulated amounts for storms, days, months, and years; intensities for each time increment; accumulative kinetic energy; storm, month, and annual summaries of amounts falling in intensity classes; maximum amounts in selected time periods; and erosion energy for each storm, defined as the accumulative kinetic energy times the maximum 30-minute intensity. Storms are normally defined as periods containing more than 0.25 inch of rain and are separated from other periods by more than 1 hour, during which less

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[1] Agricultural engineer, P. O. Box 896, Council Bluffs, Iowa 51501 and hydraulic engineer, North Central Watershed Research Center, P. O. Box 916, Columbia, Mo. 65201, respectively.

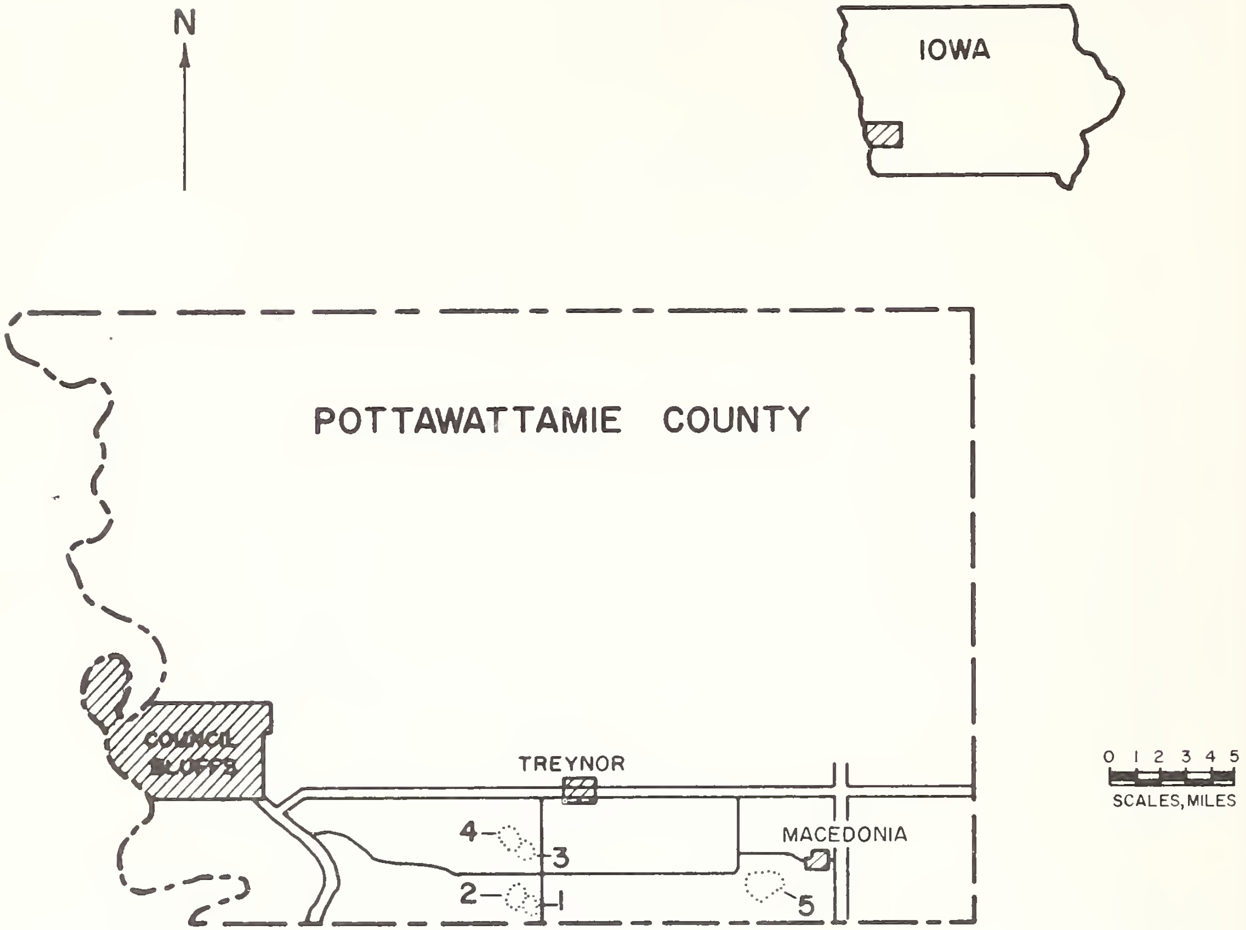

Figure 1.—Watershed locations.

than 0.01 inch of rain fell. The total computer output from 1968 to present has been stored on magnetic tape. The computer input cards and printed output are stored for data before 1968.

PRECIPITATION CHARACTERISTICS

Thunderstorms produce a significant amount of the rainfall measured by these gages. These are also the most significant rains for hydrologic and erosion research because they most often occur in the spring and summer and frequently have high intensities. Rainfall from frontal activity occurs most often in the fall months and, although the quantities are often significant, the intensities are usually low. Because these watersheds are located well within the Great Plains, there is very little topographic or orographic influence on the precipitation.

Average annual precipitation for this location, as determined by the 98-year record at Omaha, Nebr. (18 miles west), is 28.45 inches. The annual distribution shows that two-thirds of the annual precipitation occurs during the growing season, April through September. On the average, snowfall is a minor portion of the annual precipitation. The average accumulation for December through March is only 3.9 inches, although rapid snowmelt on frozen ground occasionally causes flooding.

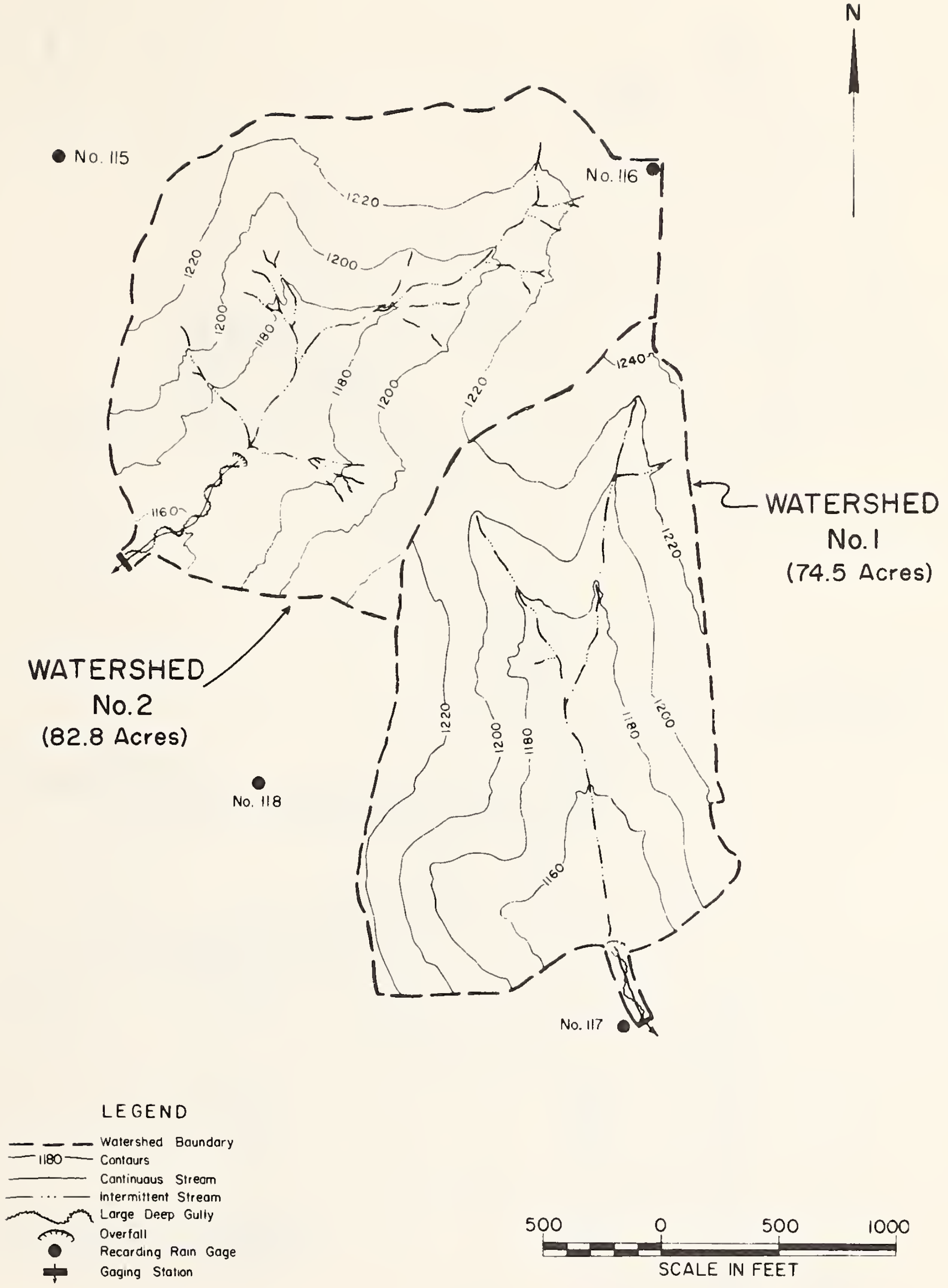

Figure 2.—Rain gage locations on watersheds 1 and 2.

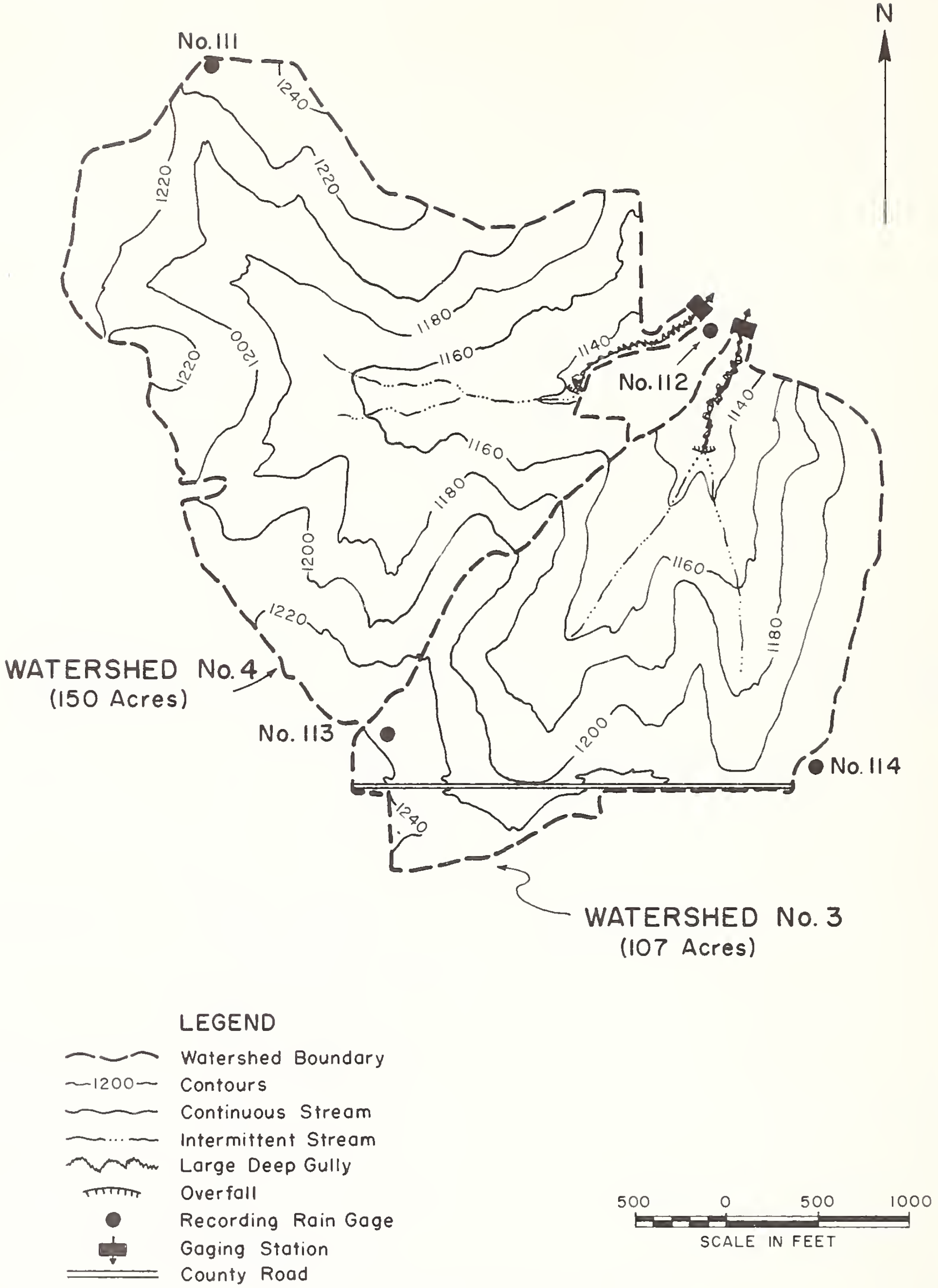

Figure 3.–Rain gage locations on watersheds 3 and 4.

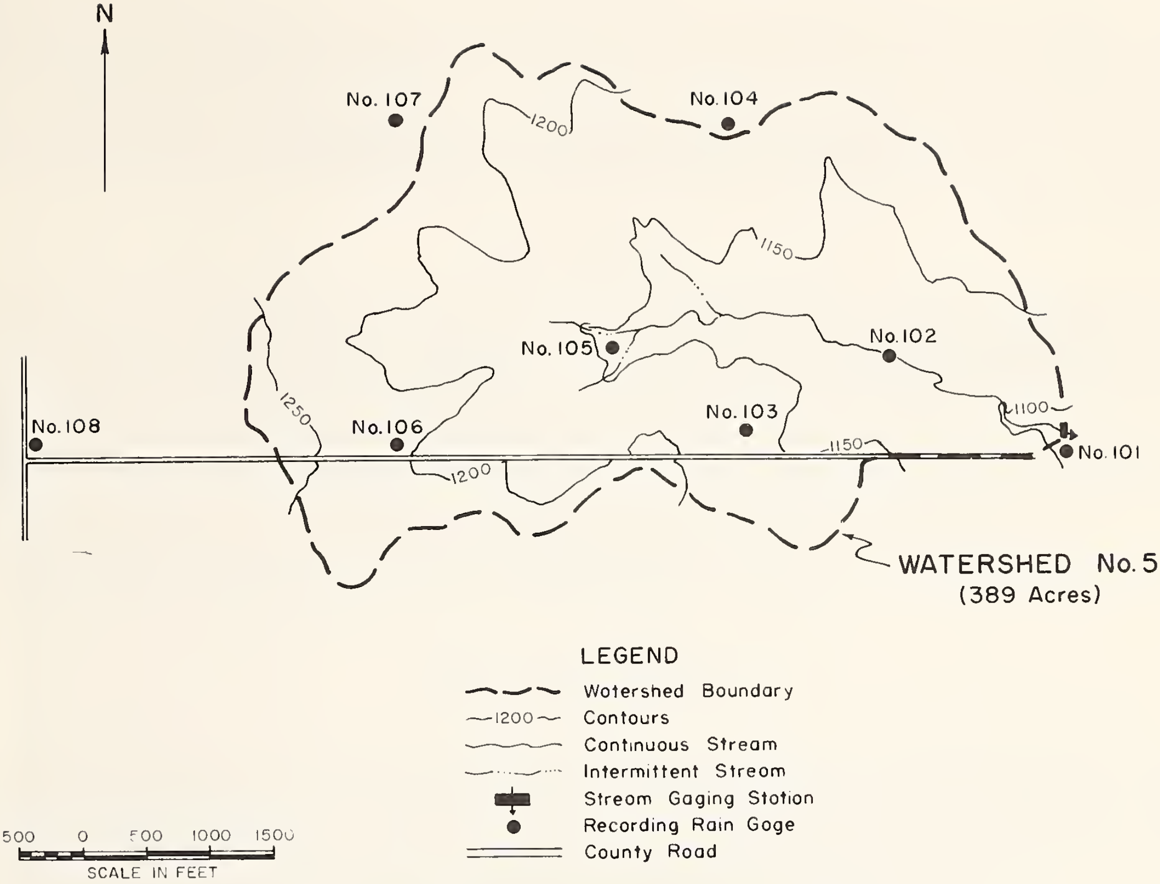

Figure 4.–Rain gage locations on watershed 5.

Table 1.–Summary of rain gage networks, Treynor, Iowa

Rain gage[1] (No.)	Date record began	Operation period		Elevation above mean sea level (Feet)	Charts		Intensity and volumes computed
		All year	Apr.-Oct.		12 hours, 9 inches	192 hours, 9 inches	
			Watersheds 1 and 2				
115	9/11/63	–	x	1,212	x	–	x
116	9/11/63	–	x	1,244	x	–	x
117	9/12/63	x		1,138	x	–	x
118	4/ 7/65	–	x	1,207	–	x	–
			Watersheds 3 and 4				
111	3/17/64	–	x	1,227	x	–	x
112	9/12/63	–	x	1,122	x	–	x
113	9/10/63	x	–	1,240	x	–	x
114	9/12/63	x	–	1,225	–	x	–
			Watershed 5				
101	2/ 6/63	x	–	1,100	x	–	x
102	4/ 4/63	–	x	1,105	x	–	–
103	3/29/63	–	x	1,190	x	–	–
104	3/28/63	–	x	1,177	x	–	–
105	7/26/63	–	x	1,150	x	–	x
106	3/28/63	–	x	1,205	x	–	–
107	3/28/63	–	x	1,244	x	–	–
108	3/29/63	x	–	1,241	–	x	–

[1] All gages are the recording type.

Rainfall for 5 of the 7 years of data (1963-69) has been above average, with extreme amounts recorded during several periods.[2,3] Rainfall in September 1965 totaled 14 inches, which exceeded all previous monthly totals in the 98-year Omaha record. However, this total was exceeded when 16 inches was recorded on the watersheds in June 1967. During a 31-day period, May 28 to June 27, 1967, 20 to 22 inches of rain fell on the watersheds. Frequency studies showed that both this 31-day amount and the largest event within this period, 6 inches in less than 3 hours, had return intervals of more than 100 years. The above-normal rainfall and extreme events have caused considerable runoff and erosion.

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[2] Piest, R. F., and Spomer, R. G. Sheet and gully erosion in the Missouri Valley loessial region. Amer. Soc. Agr. Engin. Trans. 11(6): 850-853. 1968.

[3] Saxton, K. E., and Spomer, R. G. Effects of conservation on the hydrology of loessial watersheds. Amer. Soc. Agr. Engin. Trans. 11(6): 848-849, 853. 1968.

CHAPTER 6.--OXFORD, MISS.

Andrew J. Bowie[1]

The sedimentation research project in the Pigeon Roost Creek Watershed, Marshall County, Miss., was initiated by the USDA Sedimentation Laboratory in September 1956. Studies on Toby Tubby Creek Watershed at Oxford, Miss., began during the latter part of 1959. The gaging site for this 1,000-acre urban watershed is located adjacent to the Sedimentation Laboratory. One of the primary considerations in the instrumentations of the watersheds for runoff and sediment yield investigations was to establish a rain gage network that would adequately describe precipitation events. The actual selection of rainfall gaging sites in the 117-square-mile Pigeon Roost Creek Watershed was determined to a large extent by accessibility to remote areas within the watershed.

The objectives of this study are to furnish precipitation data useful in studies of runoff, sediment yields, ground water recharge, and the potential of rainfall to cause erosion.

RAIN GAGE HISTORY

Fifteen recording and 15 nonrecording rain gages were placed on the Pigeon Roost Creek Watershed between November 21 and December 26, 1956. As shown in figure 1, these 30 gages were spaced with a density of one gage per 4 square miles over most of the watershed. During this early period, the nonrecording gages did not give the desired information on the watershed. The records from these nonrecording gages are good for monthly and annual precipitation values; however, they are not of much value in studying individual storms and intensities.

By April 1, 1958, nonrecording gages 25, 28, and 29 were replaced with recording gages. Recording rain gage 11 was moved to a new and more convenient location in the extreme southwest corner of the watershed, and recording rain gage 31 was added to the network. By July 1, 1959, all remaining nonrecording gages were replaced with recording gages. The addition of recording gage 33 on September 21, 1962, completed the rain gage network for the watershed. Recording gages 34 and 35 were later added for special studies in subwatershed 4; however, these gages are not used in the computation of rainfall for the Pigeon Roost Creek Watershed.

The precipitation studies on the Toby Tubby Creek Watershed at Oxford, Miss., began with the installation of recording rain gage 1 on November 9, 1960. This gage was installed as part of the instrumentation for a climatological station located on the USDA Sedimentation Laboratory property. Maintenance and observations are made in cooperation with the Environmental Science Services Administration (ESSA). Recording gages 2 and 3 were added August 23, 1961. The network was completed as shown in figure 2 with the addition of gages 4 and 5 on June 3, 1964.

The period of record and mean sea level elevation for each gage in the watersheds are listed in tables 1 and 2.

WATERSHED TOPOGRAPHY

Both the Pigeon Roost Creek Watershed and Toby Tubby Creek Watershed lie in the North Central Hills region of the East Gulf Coast physiographic section of the Coastal Plain province. Figure 1 shows that the Pigeon Roost Creek Watershed is shaped similar to the State of South Carolina with the major east-west axis approximately 15 miles long and with an average width of about 8 miles. Approximately 90 percent of the drainage within the corporate limits of the City of Holly Springs, Miss. is included within the watershed.

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[1] Hydraulic engineer, USDA Sedimentation Laboratory, Box 30, Oxford, Miss. 38655.

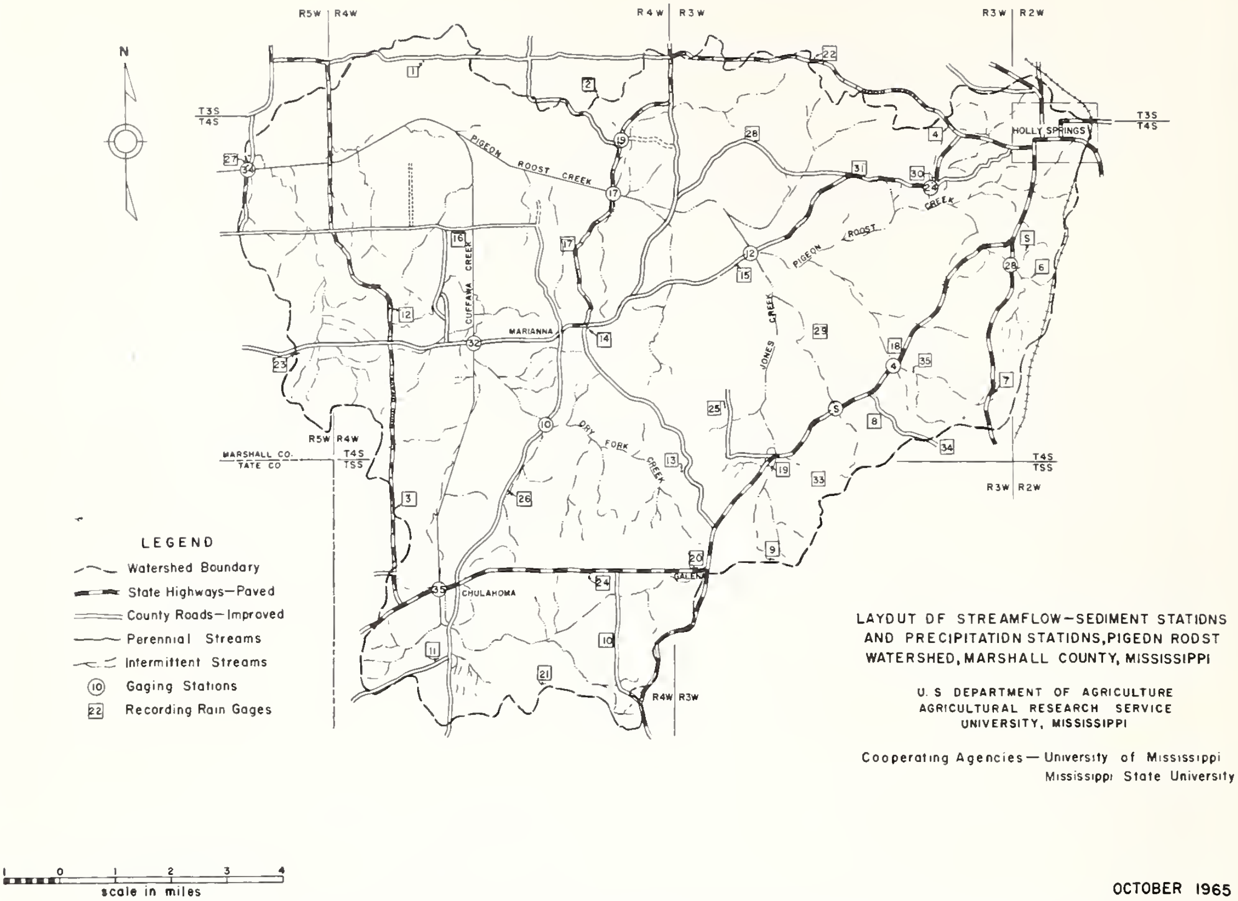

Figure 1.—Streamflow-sediment stations and precipitation stations, Pigeon Roost Creek Watershed, Marshall County, Miss.

The topographic elevation ranges from approximately 300 feet at rain gage 27 to between 500 and 600 feet on the watershed boundary. The greatest elevation (+640 feet) is located near rain gage 4 and also along the southeast boundary of the watershed near rain gage 10. The surface features consist of broad flat flood plains with both natural and dredged channels and rolling severely dissected interfluvial areas.

Approximately 22 percent of the Pigeon Roost Creek Watershed has slopes under 2 percent with 24 percent in the 2- to 5-percent range. For the remainder of the area, 8 percent is in the 5- to 8-percent range, 10 percent is in the 8- to 12-percent range, 19 percent is in the 12- to 17-percent range, and 17 percent has greater than 17 percent slope. In general, the land is severely eroded with gullies prevalent throughout the basin.

Figure 2 shows that the Toby Tubby Creek Watershed is approximately square in shape with irregular boundary. Land use surveys conducted in 1966 indicate that about 55 percent of this 1,000-acre watershed is in urban use. The topographic elevation ranges from approximately 560 feet near rain gage 3 to approximately 340 feet at the streamflow gaging site near the Sedimentation Laboratory. The greatest elevation (580 feet) is located in the northeast boundary of the watershed.

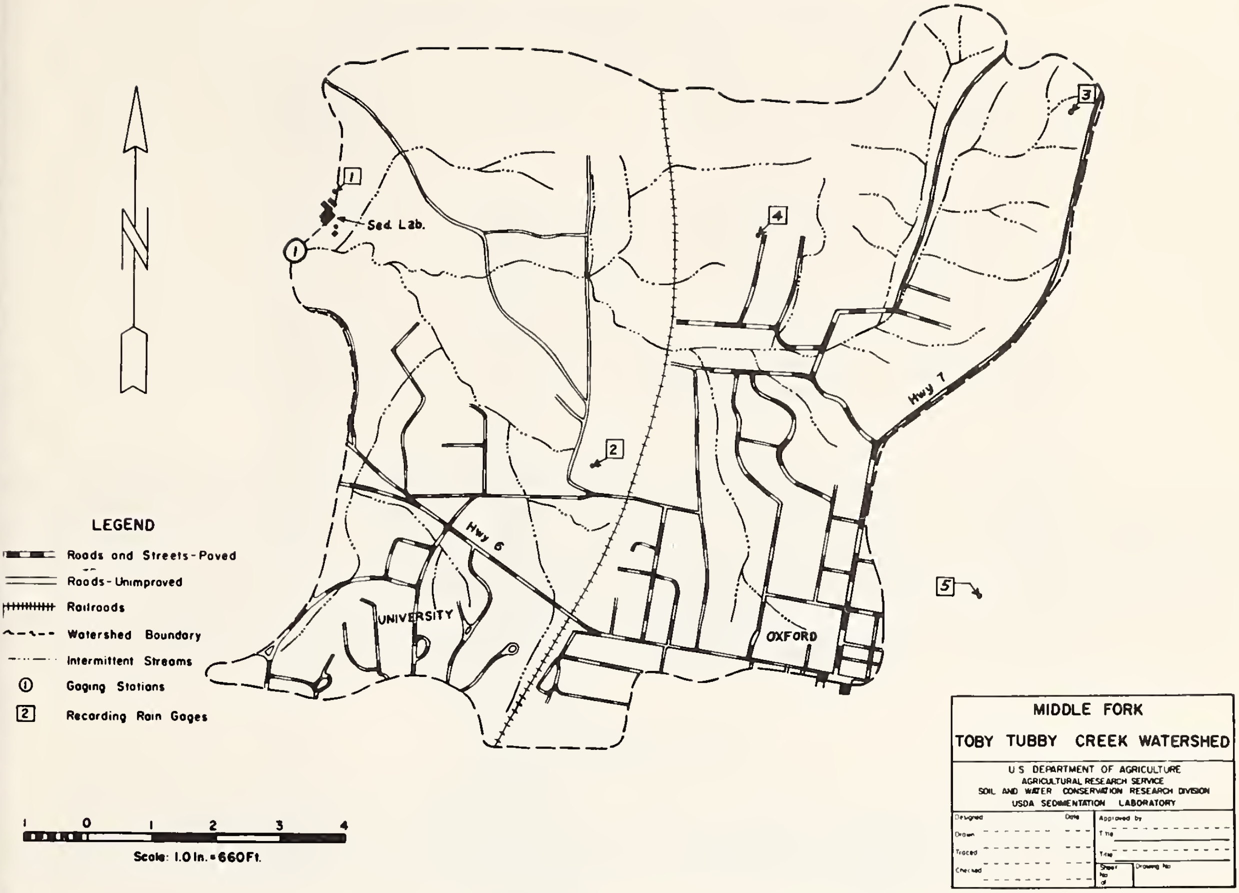

Figure 2.–Rain gage network, Middle Fork, Toby Tubby Creek Watershed, Miss.

PRECIPITATION CLIMATOLOGY

The climate of the area in which the Pigeon Roost Creek and Toby Tubby Creek Watersheds are located is determined principally by the subtropical latitude, the huge land mass to the north, and the close proximity to the warm waters of the Gulf of Mexico. Local modifications caused by variations in topography are usually not pronounced. In summer the prevailing southerly winds provide a moist tropical climate, but occasionally the atmospheric pressure distribution is such as to bring west or north winds resulting in hot dry weather. If prolonged, this may develop into droughty conditions of varying severity. In winter this area is subjected alternately to moist tropical air and dry polar air. The change from one to the other sometimes results in rather broad and sudden changes in temperature. However, cold spells are usually of short duration.

The long-term (1920-67) mean rainfall in the vicinity of the Pigeon Roost Creek Watershed is 53.99 inches. Of this amount, 30.34 inches occur during the growing season (March through September). In general, the year can be divided into two wet and two dry seasons. Winter and spring are generally wet, whereas summer and fall are generally dry, with fall the driest season. Thunderstorms occur on an average of 50 to 60 days a year, and occur more frequently in July than any other month. Those that occur in the late fall, winter, and early spring are more apt to be attended by high winds than those that occur in summer. However, in the summer, after a spell of unusually high temperatures, thunderstorms may develop with local violence and produce heavy rainfall in a very short time. An event of this type occurred on May 26, 1963, with rain gage 21 on the south boundary of the watershed recording 5.35 inches of precipitation in 2 hours. This 2-hour rainfall catch was essentially a 500-year event.

During the 13-year period of record (Jan. 1, 1957, to Dec. 31, 1969) in the Pigeon Roost Creek Watershed, maximum amounts of 0.90 inch in 8 minutes, 1.50 inches in 15 minutes, and 2.30 inches in 30 minutes have been

Table 1.—Rain gage network in the Pigeon Roost Creek Watershed

Rain gage No.	Period of record	Type of gage	Estimated elevation above mean sea level
			Feet
1	Nov. 1956 to present	Recording	435
2	---- do --------------	---- do -------	510
3	---- do --------------	---- do -------	470
4	---- do --------------	---- do -------	595
5	---- do --------------	---- do -------	545
6	---- do --------------	---- do -------	520
7	Dec. 1956 to present	---- do -------	555
8	Nov. 1956 to present	---- do -------	525
9	---- do --------------	---- do -------	545
10	---- do --------------	---- do -------	550
11	---- do --------------	---- do -------	460
12	---- do --------------	---- do -------	450
13	---- do --------------	---- do -------	515
14	---- do --------------	---- do -------	500
15	---- do --------------	---- do -------	410
16	Nov. 1956 to June 1959 July 1959 to present	Nonrecording Recording	400
17	Dec. 1956 to June 1959 July 1959 to present	Nonrecording Recording	435
18	---- do --------------	Nonrecording Recording	505
19	---- do --------------	Nonrecording Recording	490
20	---- do --------------	Nonrecording Recording	565
21	---- do --------------	Nonrecording Recording	525
22	---- do --------------	Nonrecording Recording	553
23	---- do --------------	Nonrecording Recording	425
24	---- do --------------	Nonrecording Recording	550
25	Dec. 1956 to Mar. 1958 Apr. 1958 to present	Nonrecording Recording	470
26	Dec. 1956 to June 1959 July 1959 to present	Nonrecording Recording	500
27	---- do --------------	Nonrecording Recording	315
28	---- do --------------	Nonrecording Recording	520
29	---- do --------------	Nonrecording Recording	485
30	---- do --------------	Nonrecording Recording	465
31	Apr. 1958 to present	---- do -------	565
33	Sept. 1962 to present	---- do -------	550
34	Aug. 1965 to present	---- do -------	565
35	---- do --------------	---- do -------	470

Table 2.—Rain gage network in the Toby Tubby Creek Watershed

Rain gage No.	Period of record	Type of gage	Estimated elevation above mean sea level
			Feet
1	Nov. 9, 1960 to present	Recording	360
2	Aug. 23, 1967 to present	----do----	380
3	----do----	----do----	560
4	June 3, 1964 to present	----do----	540
5	----do----	----do----	500

recorded. During late fall, winter, and early spring, thunderstorms may occur at any time of day, as they are usually associated with passing weather systems. During the summer months or warm season, about 65 percent of the thunderstorms occur between noon and 1800 hours, and 85 percent between noon and midnight. Winter season storms are typified by moderate rainfall intensities but relatively large total volumes of precipitation. Extended periods of precipitation totaling more than 2 inches occur frequently during the winter months. Although measurable snow falls in the watershed at least once in three out of four winters, it contributed very little runoff.

DATA REDUCTION

An automatic chart reader is used to convert the rainfall hydrograph from analog to digital form. During the early part of 1963, a program was written for the IBM 1620 computer to process these data. This program was rewritten in 1969 for the IBM 360 computer with the output consisting of the following:

1. Amount, intensity, and duration of rainstorms.
2. Precipitation amounts for each station by constant time intervals (beginning on the hour by each 2, 5, 10, or 15, 30, and 60 minutes) and by storm, day, month, and year.
3. Maximum rainfall intensities during each storm for 2, 5, 10, 15, 20, and 30 minutes, and 1, 2, 4, 6, 12, and 24 hours.
4. Precipitation data arranged in a form most useful for further analysis with or without digital computers.

The computer output as listed above has been completed for all of the Pigeon Roost Creek network for 1962 and 1963. Interval breakpoints have been listed and placed on punchcards for 1964, 1965, 1966, and 1968. The daily precipitation for each individual gage for the entire period of record has been placed on punchcards; also, the monthly Thiessen-weighted precipitation for all subwatersheds within the study area have been computed for 1957 through 1969. The monthly Thiessen-weighted precipitation for the Toby Tubby Creek Watershed has been computed for 1962 through 1969.

COMMENTS

There is a long-term precipitation record for the ESSA gage at the North Mississippi Branch Experiment Station located 2 miles north of Holly Springs, Miss. The normal precipitation was computed from 48 years of record at this station and compared to the shorter record on the nearby Pigeon Roost Creek Watershed.

Table 3 and figure 3 show the average monthly and annual precipitation for different parts of the watershed. The Thiessen-weighted precipitation for the entire watershed and the 48-year record from the ESSA station are also listed in table 3.

RG-14 near the center of the watershed has recorded more precipitation than any other gage in the watershed. This average of 54.74 inches is above the 13-year average of 50.46 inches and the 48-year average (1920-67) of 53.99 at the ESSA station. The period of record is too short, however, to risk any conclusions as yet. The long-range

Table 3.—Average monthly and annual precipitation for the Pigeon Roost Creek Watershed (1957-69)

Rain gage No.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total annual	Monthly average
	Inches													
RG-1.	3.96	4.66	4.74	5.36	4.11	3.11	4.08	4.63	4.74	1.97	4.18	5.53	51.07	4.26
RG-5.	3.69	4.59	4.56	4.63	4.08	3.10	3.90	3.68	4.37	2.25	4.37	5.21	48.43	4.04
RG-9.	3.81	4.73	4.80	4.94	4.41	2.90	3.75	3.79	5.03	2.51	4.55	5.50	50.72	4.23
RG-11.	3.87	4.75	4.82	4.94	4.34	3.02	4.03	3.25	4.82	2.13	4.45	5.51	49.93	4.16
RG-12.	3.72	4.57	4.70	5.05	4.06	2.86	3.96	4.46	4.62	2.08	4.19	5.42	49.69	4.14
RG-14.	4.40	5.42	5.28	5.28	4.55	3.12	4.23	4.67	4.45	2.44	4.86	6.04	54.74	4.56
RG-15.	4.00	4.89	4.92	5.08	4.43	3.07	4.22	4.53	4.24	2.24	4.59	5.58	51.79	4.32
RG-22.	3.96	4.94	4.68	5.12	4.25	2.67	4.06	4.59	4.54	2.20	4.20	5.46	50.67	4.22
RG-27.	4.03	4.75	4.71	5.20	4.25	2.91	3.97	4.77	4.48	2.06	4.14	5.44	50.71	4.23
Watershed[1].	3.91	4.76	4.78	4.99	4.29	2.99	4.05	4.11	4.59	2.17	4.36	5.46	50.46	4.20
Normal P[2] .	5.67	5.27	5.93	5.06	4.66	3.76	4.40	3.27	3.45	2.88	4.51	5.13	53.99	4.50

[1] Thiessen-weighted.

[2] Normal P based on 48-year record (1920-67) at ESSA station 2 miles north of Holly Springs, Miss.

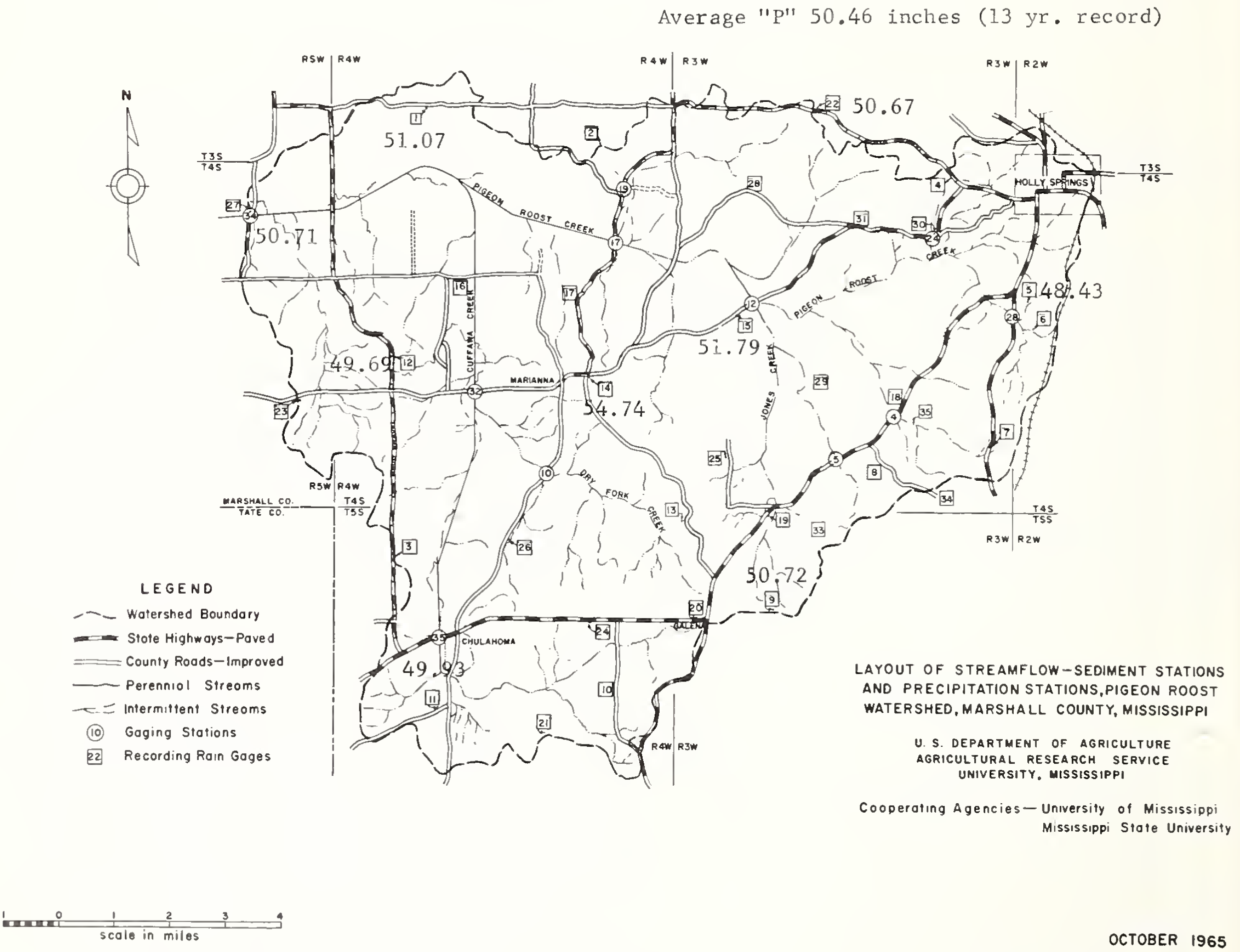

Figure 3.—Streamflow-sediment stations and precipitation stations, Pigeon Roost Creek Watershed, Miss. Average precipitation = 50.46 inches (13-year record).

monthly averages do not agree with the monthly averages for the 13-year period; therefore, this 13-year period may have abnormal precipitation distribution by gages as well as by months.

The monthly precipitation from the long-range record is shortest for March, followed by January, February, December, April, May, November, July, June, September, August, and October. For the Pigeon Roost Creek Watershed, the decreasing order by months is December, April, March, February, September, November, May, August, July, January, June, and October. The long-term record indicates that December, January, and February fit together well as the winter quarter of record. December should definitely be listed as a winter month, whereas November and March are transitional months and should probably be studied separately.

Table 4 shows the maximum and minimum monthly and annual precipitation for the same rain gages listed in table 3.

Precipitation for several storms was computed by isohyetal and Thiessen methods. The two methods are compared by the figures in table 5. Precipitation was computed for all stream-gaged watersheds and subwatersheds in the Pigeon Roost Creek Watershed. When studying and comparing the figures in table 5, it must be remembered that the rain gages are not necessarily centered in or evenly distributed throughout a subwatershed. The largest errors introduced by the Thiessen method occur for heavy convective storms centered along the boundary of the Pigeon Roost Creek Watershed. Normally, local errors in the Thiessen method are cancelled out in the larger watersheds, but this is not true for boundary storms. In general, the errors introduced by the Thiessen method for these boundary storms are carried through the Thiessen computations for the entire watershed, although the magnitude of the error diminishes with the increase in watershed area. Except for these boundary storms, the isohyetal method shows the Thiessen method to be fairly consistent for all the stations on the Pigeon Roost Creek Watershed.

Table 4.—Monthly and annual maximum-minimum precipitation for Pigeon Roost Creek Watershed (1957-69)[1]

Rain gage No.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total annual
	Inches												
RG-1	7.63	8.34	8.95	10.48	10.33	9.09	6.81	7.74	11.44	4.70	9.70	10.23	68.44
	.79	1.76	1.82	1.90	1.69	.85	.50	1.62	.89	.00	1.34	1.74	40.85
RG-5	7.91	8.27	10.00	10.06	6.86	6.96	6.58	8.38	9.52	5.29	9.34	8.42	61.09
	.93	1.44	1.71	1.01	1.35	.41	.41	.89	.66	.00	1.22	1.23	39.44
RG-9	7.68	8.99	10.17	9.52	8.97	5.67	7.85	6.41	10.61	5.30	9.71	9.41	64.33
	.63	1.51	1.56	1.03	1.72	.46	.38	.49	1.29	.00	.95	1.70	39.27
RG-11	7.58	8.91	9.74	9.25	9.32	7.17	8.75	8.05	9.43	5.05	9.72	9.86	63.75
	.59	1.86	1.42	1.56	1.83	.98	.91	1.01	1.27	.00	1.06	1.66	39.55
RG-12	7.70	7.53	8.98	9.60	7.83	7.09	8.45	8.09	11.94	4.37	9.68	9.15	66.50
	.75	1.64	1.67	1.37	1.81	.98	.48	.76	.97	.47	.92	1.52	40.90
RG-14	9.29	9.24	10.46	9.97	7.70	7.89	7.90	8.77	10.23	5.63	11.24	9.73	74.17
	1.03	2.02	1.95	1.35	2.04	.57	.30	.94	1.19	.29	1.21	1.69	43.61
RG-15	7.63	8.70	8.16	10.67	8.21	7.15	8.17	9.19	10.27	5.05	9.12	9.90	64.95
	1.00	1.44	1.88	1.23	2.39	.42	1.34	.73	1.31	.15	1.33	1.39	42.27
RG-22	7.82	7.72	10.76	9.84	8.06	5.86	8.15	8.00	10.56	4.38	8.93	9.18	64.91
	.77	1.81	1.97	1.42	1.88	.70	1.65	1.40	1.33	.00	1.14	1.40	38.31
RG-27	8.42	8.64	8.75	10.68	9.33	6.12	10.02	7.62	13.03	4.64	9.30	10.24	65.52
	.76	1.85	2.09	1.59	1.43	.62	.11	1.96	.74	.00	1.05	1.68	40.41
Watershed[2]	7.92	8.28	9.90	9.55	8.39	6.77	8.60	7.74	10.20	4.59	9.41	9.10	65.72
	.77	1.78	1.70	1.23	2.04	.69	1.32	1.18	1.15	.06	1.36	1.56	41.87

[1] Maximum annual precipitation for the watershed occurred in 1957; minimum, in 1963.
[2] Thiessen-weighted.

Table 5.–Isohyetal-Thiessen comparison, Pigeon Roost Creek Watershed

Subwatershed	Area (acres)	Nov. 13, 1957		Apr. 3, 1958		Sept. 20, 1958		June 11, 1959		Dec. 11, 1959		Mar. 2, 1960	
		P_t	P_i[1]	P_t	P_i	P_t	P_i	P_t	P_i	P_t	P_i	P_t	P_i
19[2]	243	2.43	2.44	0.99	0.98	2.41	2.35	0.76	0.75	2.75	2.68	1.34	1.38
24	512	2.57	2.58	.88	.90	1.81	1.88	1.27	1.24	2.45	2.50	1.46	1.40
28	1,080	3.20	3.26	1.28	1.35	2.42	2.42	1.15	1.26	2.66	2.68	1.67	1.72
5	1,130	2.94	2.98	1.67	1.65	2.50	2.54	1.49	1.44	2.58	2.59	1.79	1.82
4	1,580	3.31	3.24	1.60	1.59	2.49	2.46	1.41	1.38	2.64	2.65	1.80	1.82
35	7,550	2.94	2.97	2.25	2.14	2.44	2.43	.89	.94	2.91	2.87	1.87	1.94
32	20,000	2.81	2.87	1.91	1.89	2.36	2.34	.94	.98	2.88	2.83	1.80	1.83
12	22,800	2.88	2.86	1.27	1.28	2.36	2.28	1.12	1.16	2.60	2.56	1.65	1.67
17	32,100	2.74	2.68	1.14	1.14	2.29	2.23	1.01	1.03	2.63	2.60	1.58	1.60
34	75,000	2.60	2.69	1.31	1.29	2.30	2.26	.92	.92	2.77	2.75	1.58	1.62

[1] P_t = Precipitation computed by the Thiessen method;
P_i = Precipitation computed by the isohyetal method.
[2] Studies discontinued Sept. 30, 1965.

SUMMARY

Precipitation studies conducted by the USDA Sedimentation Laboratory in northern Mississippi consist of a rain gage network of 32 recording gages in the Pigeon Roost Creek Watershed in Marshall County and five recording gages in the Toby Tubby Creek Watershed at Oxford. Precipitation data have been collected for 13 years on the Pigeon Roost Creek Watershed and 9 years on the Toby Tubby Creek Watershed. The IBM 360 computer is used to compute the desired output. A long-term (48 years) precipitation record, collected at a nearby ESSA station, is available for comparison with the Pigeon Roost Creek precipitation data.

Precipitation for several storms was computed by the isohyetal and Thiessen methods. In a comparison of the two methods, it was determined that a certain amount of discrepancy was induced by the Thiessen method for heavy convective storms centered along the watershed boundary. For most storms, however, the Thiessen method is considered to be fairly accurate and is used to compute the precipitation for each of the subwatersheds in the study area.

CHAPTER 7.--EKALAKA, MONT.

Earl L. Neff[1]

In 1967, the Agricultural Research Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, entered into a cooperative agreement to study the effects of selected range management practices on the hydrology and vegetation of panspot and saline upland range sites in southeastern Montana. Incidental to such an investigation is the establishment and operation of a dense network of rain gages to provide quantitative measurements of precipitation input to the research sites.

The research site is located approximately 15 miles south of Ekalaka, Carter County, Mont. Two-acre watersheds are constructed on three representative research sites, each characteristic of one main soil-vegetation complex found in saline upland and panspot ranges. Site 1 has five watersheds, and sites 2 and 3 have six watersheds each. Precipitation input to each site is measured by a network of recording and nonrecording gages. The network at site 1 (fig. 1) consists of six recording and 11 nonrecording gages installed with the orifices approximately 40 inches above the ground surface. At each of sites 2 (fig. 2) and 3 (fig. 3), there are seven recording and 12 nonrecording gages. Also, at each site recording pit gages are installed with the orifices at ground level to measure the differences in catch due to wind influence.

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[1] Research hydraulic engineer, Northern Plains Soil and Water Research Center, P.O. Box 1109, Sidney, Mont. 59270.

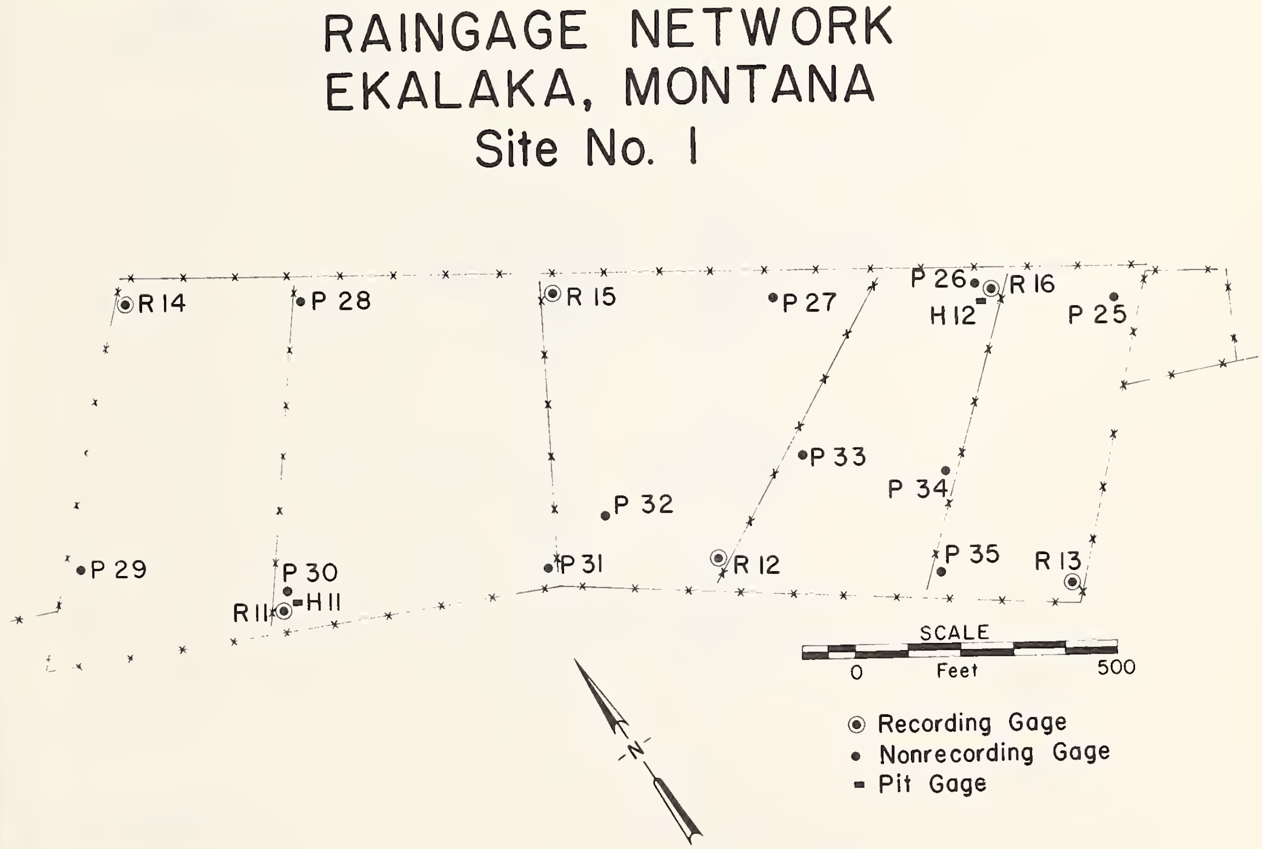

Figure 1.–Rain gage network at site 1, frail land study, Ekalaka, Mont.

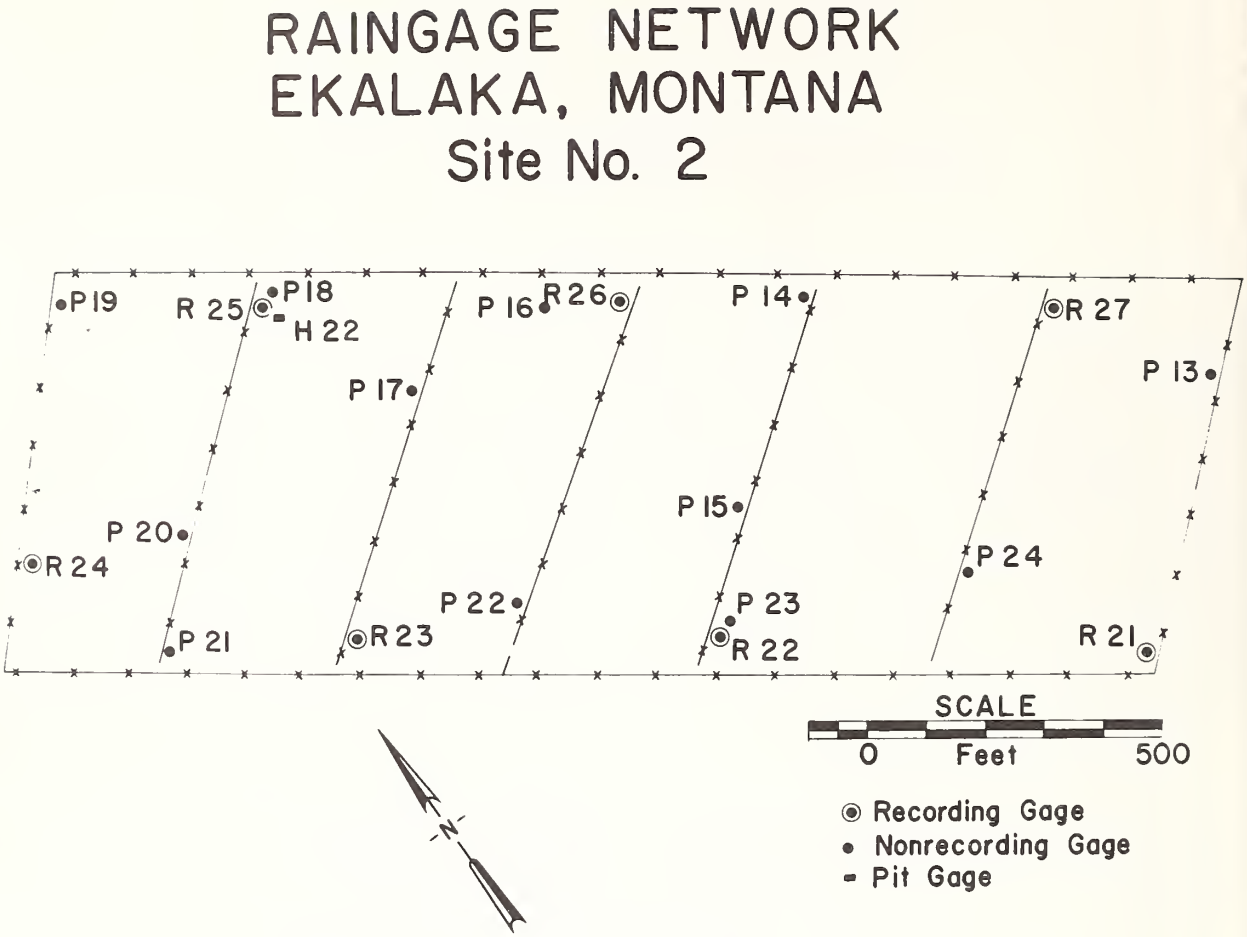

Figure 2.—Rain gage network at site 2, frail land study, Ekalaka, Mont.

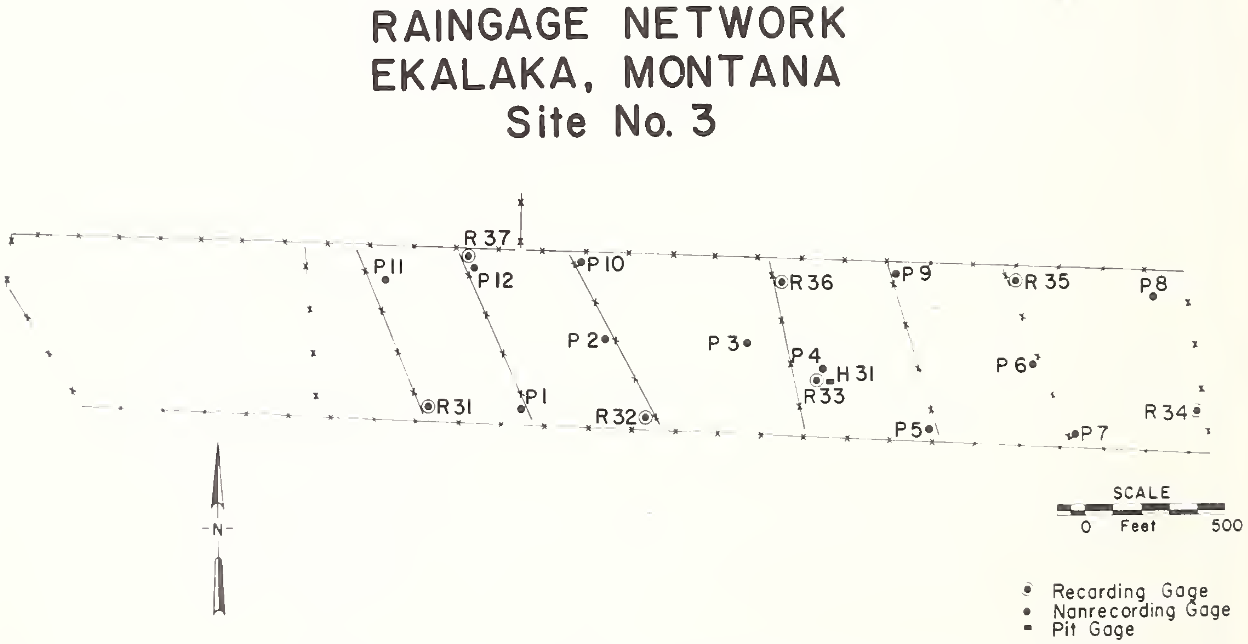

Figure 3.—Rain gage network at site 3, frail land study, Ekalaka, Mont.

The recording rain gages are Fischer and Porter weighing type, Model 15-59-EA-1-4, with 8-inch orifices and paper tape punch-out at 5-minute intervals. The nonrecording gages are clear plastic with 3.95-inch orifices and an interior cylinder that provides a 10:1 magnification of the catch.

The watersheds are located on fairly flat, uniform slopes. On site 1, the average slope is 2 percent; on site 2, it is 5 percent; and on site 3, it is 1 percent. The nearest established benchmark is approximately 15 miles from the research sites, so no elevations based on mean sea level data have been determined. The approximate elevation of site 3 is 3,400 feet above mean sea level.

Site 1 is approximately 1 mile west-southwest of site 3 and 35 feet higher. Site 2 is about 1½ miles west of site 3 and 70 feet higher. The maximum difference in elevation within each site is about 20 feet.

The areas selected are representative of many similar range sites under both private ownership and Bureau of Land Management administration that are identified as "frail lands." In terms of reference of this study, frail lands are defined as rangelands consisting of (1) solodized Solonetz soils, (2) raw shale soils, and (3) Solonchak soils, all of which have developed under annual precipitation of 8 to 15 inches. These lands are low in productivity because of inherent soil deficiencies and overuse by wild animals and domestic livestock. The principal study objective is to evaluate contour furrowing effects on hydrologic characteristics, vegetation ecology, and soil physical and chemical properties.

The network was placed in operation during the summer of 1968. Because access to the research area for routine servicing and maintenance of gages is difficult during the winter months, only a skeleton network is in operation year around. From November through March each year, all of the nonrecording gages and most of the recording gages are taken out of operation. Two recording gages are left in operation all year at each of the three sites. Tables 1, 2 and 3 list information on the gage network at the Ekalaka project. The data from the recording gages are on paper punch tape in ASCII[2] code. Data from the nonrecording gages are tabulated by dates of servicing.

Table 1.—Network information, site 1

[NE¼ sec. 8, T. 25, R.58 E. Carter County, Mont.]

Gage type and No.	Dates of operation		Remarks
	1968	1969	
Recording:			
R11	8/13-12/31	1/1-12/31	
R12	8/13-10/24	4/7-10/22	
R13	8/13-10/24	4/7-9/16	Mechanical failure 9/16/69
R14	7/11-12/31	1/1-10/22	
R15	7/11-10/24	4/7-5/20	Mechanical failure 5/20/69
R16	8/13-10/24	4/7-12/31	
H11	7/13-10/24	4/22-10/23	
H12	7/13-10/24	4/22-10/23	
Nonrecording:			
P25	7/31-9/23	4/23-10/22	
P26	–	5/20-10/22	
P27	7/31-9/23	5/20-10/22	
P28	7/31-9/23	4/23-10/22	
P29	8/6-9/24	4/23-10/22	
P30	8/7-9/24	4/23-10/22	
P31	8/7-9/24	4/23-10/22	
P32	8/7-9/24	4/23-10/22	
P33	8/7-9/24	4/23-10/22	
P34	8/7-9/24	4/23-10/22	
P35	8/7-9/24	4/23-10/22	

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[2] American Standard Code II.

Table 2.–Network information, site 2

[NE¼ sec. 6, T 25 R.58 E. Carter County, Mont.]

Gage type and No.	Dates of operation		Remarks
	1968	1969	
Recording:			
R21	5/15-12/31	1/1-12/31	
R22	5/22-10/24	4/7-10/23	
R23	7/31-10/24	4/7-10/23	
R24	7/31-12/31	1/1-1/16	Mechanical failure 1/16/69-2/11/69
	–	2/11-10/23	
R25	7/31-10/24	4/7-12/31	
R26	7/31-10/24	4/7-10/23	
R27	7/31-12/31	1/1-1/16	Mechanical failure 1/16/69-3/26/69
	–	3/26-10/23	
H21	8/1-9/1	([1])	Pit flooded 1969
H22	8/1-10/24	4/22-10/23	
Nonrecording:			
P13	8/1-9/24	4/23-10/22	
P14	8/1-9/24	4/23-10/22	
P15	8/1-9/24	4/23-10/22	
P16	8/1-9/24	4/23-10/22	
P17	8/1-9/24	4/23-10/22	
P18	8/1-9/24	4/23-10/22	
P19	8/1-9/24	4/23-10/22	
P20	8/1-9/24	4/23-10/22	
P21	8/1-9/24	4/23-10/22	
P22	8/1-9/24	4/23-10/22	
P23	8/1-9/24	4/23-10/22	
P24	8/1-9/24	4/23-10/22	

[1] No record.

Table 3.–Network information, site 3

[NE¼ sec. 9 and NW¼ sec. 10, T.25, R. 58 E. Carter County, Mont.]

Gage type and No.	Dates of operation		Remarks
	1968	1969	
Recording:			
R31	5/28-12/31	1/1-1/16	Mechanical failure 1/16/69.
R32	5/28-10/23	4/21-10/22	
R33	5/28-12/31	1/1-1/16	Mechanical failure 1/16/69-4/21/69.
	–	4/21-7/16	
R34	5/28-12/31	1/1-10/22	
R35	6/4-10/23	([1])	Mechanical failure 1969.
R36	6/4-10/23	4/21-10/22	
R37	5/28-10/23	4/21-12/31	
H31	7/31-10/23	([1])	Pit flooded 1969.
H32	7/31-9/1	([1])	Do.
H31(new)	–	([1])	New pit prepared for 1970.
Nonrecording:			
P1	7/30-9/23	4/23-10/22	
P2	7/30-9/23	4/23-10/22	
P3	7/30-9/23	4/23-10/22	
P4	7/30-9/23	4/23-10/22	
P5	7/31-9/23	4/23-10/22	
P6	7/30-9/23	4/23-10/22	
P7	7/30-9/23	4/23-10/22	
P8	7/30-9/23	4/23-10/22	
P9	7/30-9/23	4/23-10/22	
P10	7/30-9/23	4/23-10/22	
P11	7/31-9/23	4/23-10/22	
P12	7/30-9/23	4/23-10/22	

[1] No record.

The short period of record at the frail land research area prohibits climatic classification or precipitation characterization. However, some inference can be drawn from the records at Ekalaka, 15 miles north of the research area. Annual precipitation has ranged from about 6 inches in 1936 to over 22 inches in 1963, with the average annual amount being about 14 inches. Almost 80 percent of the annual precipitation results from convective storm activity during the warm season, April through September, with the months of May and June averaging about 2.5 inches each.

The maximum rainfall intensity recorded at the research area occurred at site 2 on July 15, 1969, at which time 1 inch of rain fell between 1540 and 1545 mountain standard time. The intensity in this storm may have exceeded 12 in./hr., because the gages punch at 5-minute intervals, and there is no way of determining in which part of the 5-minute interval most of the rain occurred.

This network is designed to provide quantitative measurements of precipitation input to small areas for intensive hydrologic investigations. When the network has been operated long enough to provide a good measure of precipitation variability within sites, it will be reduced to only those gages necessary to measure input within acceptable limits.

CHAPTER 8.--ALAMOGORDO CREEK, N. MEX.

D. L. Chery and H. B. Osborn[1]

The rain gage network of the Alamogordo Creek Experimental Watershed is part of a comprehensive research program to (1) determine the future water yield potential of semiarid rangeland watersheds in the Southwest as related to measures for their conservation and sustained production of forage, (2) determine optimum utilization of water yield for local and downstream uses, and (3) obtain information needed for planning and designing measures for flash flood and sediment damage control. Within these general objectives, one study was concentrated on the precipitation received by the watershed.

The specific objectives of the precipitation study are—

1. To develop methods for evaluating rainfall amounts and rates for semiarid rangelands in the intermountain and high plains regions of the Southwest.
2. To determine seasonal distribution of precipitation for these areas.
3. To determine frequency of storms and expectancies of amount and areal extent for these areas.
4. To determine pertinent characteristics of rainfall with respect to runoff and sediment movement from these areas.

WATERSHED TOPOGRAPHY

The Alamogordo Creek Experimental Watershed is located on the western edge of the Llano Estacado about 35 miles east of Santa Rosa, N. Mex. The watershed consists primarily of a flat, recessed basin almost entirely surrounded by a steep escarpment. Most of the rain gages are located on the floor of the basin, but a few are scattered along the rim. There is a difference of 300 to 500 feet between the elevation of the basin floor and the surrounding plateau.

Figure 1 shows rain gage locations for the Alamogordo Creek Experimental Watershed, and table 1 lists the elevation, type, recording chart scales, and a period of record history for each rain gage.

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[1] Research hydraulic engineers, Southwest Watershed Research Center, 442 East Seventh Street, Tucson, Ariz. 85705.

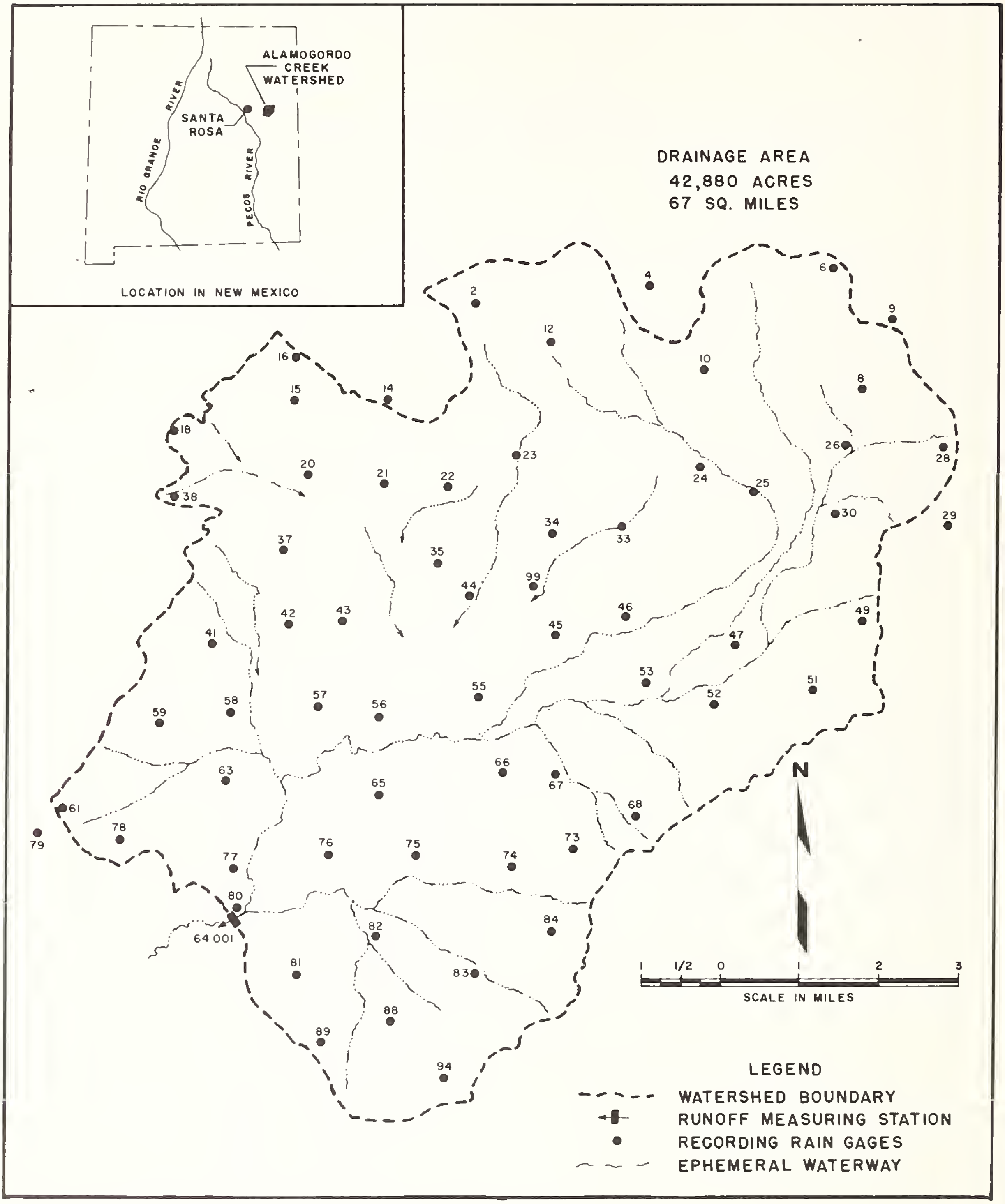

Figure 1.–Alamogordo Creek Experimental Watershed, Santa Rosa, N. Mex., rain gage network, 1969.

Table 1.–Rain gages in Alamogordo, N. Mex., January 1970

Gage No.[1]	Elevation above mean sea level (±10 feet)	History	
		Gage installed	Periods of no record
	Feet	*Date*	
64.002	5,580	6-01-55	
64.004	5,580	7-24-61	
64.006	5,590	6-01-55	
64.008	—	5-17-60	12/5/60-1/2/61
64.009	—	8-07-61	11/8/60-12/31/62 1/1/62-12/31/62
64.010	5,480	6-01-55	1/1/64-6/15/64
64.012	4,870	6-01-55	12/20/62-5/28/63
64.014	5,540	9-10-57	12/20/62-3/12/63
64.015	4,980	12-1-54	
64.016	—	2-02-66	
64.018	5,250	5-05-55	
64.020	—	9-13-57	
64.021	—	6-02-55	4/17/62-7/9/62
64.022	4,920	9-13-57	
64.023	5,010	12-1-54	12/17/62-5/28/63
64,024	—	7-18-61	11/13/62-5/28/63
64.025	5,090	6-08-55	
64.026[2]	5,130	12-1-54	
64.028	—	9-10-57	
64.029	—	7-19-61	
64.030	—	7-10-57	3/11/63-5/28/63
64.033	—	9-24-57	
64.034	—	7-10-57	12/3/58-4/10/59
64.035	4,870	6-03-55	
64.037	4,930	6-02-55	12/30/62-2/12/63
64.038[2]	5,250	3-01-66	
64.041	4,810	6-02-55	11/2/55-7/9/57
64.042	—	5-26-58	
64.043	4,800	6-02-55	
64.044	—	9-10-57	4/17/62-7/9/62
64.045	4,880	6-03-55	
64.046	4,900	7-10-57	11/21/61-4/23/62
64.047	4,960	6-02-55	
64.049	5,110	5-09-55	11/21/61-7/9/62
64.051	—	9-24-57	11/13/61-3/11/63
64.052	—	5-27-58	12/20/62-5/28/63
64.053	4,880	12-1-54	
64.055	4,800	6-03-55	11/18/63-6/22/64 11/14/62-5/27/63
64.056	—	7-09-57	8/17/60-11/29/60
64.057	4,780	6-02-55	12/20/62-2/13/63
64.058	—	9-10-57	
64.059	4,900	6-02-55	2/23/62-7/11/62
64.061	—	5-14-57	7/22/60-9/27/60
64.063	4,780	6-02-55	12/20/62-2/13/63
64.065	4,870	12-1-54	
64.066	4,800	6-04-56	4/17/62-7/9/62
64.067	4,920	5-31-55	
64.068	—	5-28-58	7/12/60-12/31/60 11/13/62-5/28/63 11/18/63-6/22/64
64.073	—	8-12-57	
64.074	4,890	5-31-55	3/6/64-6/15/64
64.075	—	7-08-57	
64.076	4,720	6-03-55	
64.077	—	5-13-57	
64.078	4,880	12-2-54	
64.079	—	8-14-63	
64.080	4,700	9-22-54	

See footnotes at end of table.

Table 1.—Rain gages in Alamogordo, N. Mex., January 1970—Continued

Gage No.[1]	Elevation above mean sea level (±10 feet)	History	
		Gage installed	Periods of no record
	Feet	*Date*	
64.081	—	7-03-57	
64.082	4,760	12-1-54	
64.083	4,910	6-06-55	
64.084	—	7-03-57	
64.088	—	7-03-57	4/23/62-7/9/62
64.089	4,870	6-06-55	12/26/62-3/11/63
64.094	4,940	6-06-55	11/14/62-3/11/63
64.099	—	6-14-65	

[1] All gages are the recording-weighing type. Time scale: 24 hs. rev. with 1 inch = 125.22 min., except as footnoted. Depth scale of gages: 1 inch = 1 inch of rain.

[2] Time scales of rain gages 64.026 and 64.038 were changed from 24 to 12 hr. rev. on April 3, 1967, and March 13, 1967, respectively, with 1 inch = 62.61 min.

PROCESSING STATUS

The precipitation record (for all gages) from the beginning of record through 1968 has been processed by the procedure described in the following section. The data have yet to be given a final computer check and then be processed by a computer tabulation program. These two operations should be completed during 1970. The final tabulations will be recorded in printed and tape output, and the printed output will be kept in the data library of the Tucson office and will contain the following information:

1. For each precipitation event:
   - A. Watershed and rain gage identification
   - B. Date
   - C. Time [military (standard), elapsed, and increment]
   - D. Depths (accumulated and increment)
2. For significant precipitation events:
   - A. Rainfall intensity for each time increment
   - B. Maximum accumulated depths of rainfall per selected time interval
   - C. First moment about the beginning time of the rainfall histogram
3. Summation of daily rainfall amount by gage
4. Summation of monthly rainfall amount by gage
5. Summary tables (raw monthly and annual totals plus several weighted monthly and annual totals for the entire set of rain gages)

The contents of the output tape are a duplication of the printed output.

The same procedures are used for processing these data as are used to process the precipitation data for the Walnut Gulch watershed. Refer to the description of these processes in the sections "Data Acquisition and Processing Procedure" and "Comments on the Gage-Processing System" in chapter 1—Walnut Gulch, Ariz.

Since 1967, all estimates have been noted in the record. As the data are processed by the tabulation program, a tally is made of the amount of estimation in the record for each gage. This information is used as an evaluation of the quality of the record and to advise the field crews which gages need servicing or how procedures should be improved. Since the tabulations for Alamogordo Creek have not, as yet, been prepared, the estimation summary is not available. However, reference can be made to the "Comments" in the report for Walnut Gulch for a discussion of the estimation tally for that location.

PRECIPITATION AND CLIMATOLOGY

In eastern New Mexico, the precipitation is seasonal, with the greater portion falling during the growing season, from May to October. Most of the winter precipitation occurs as low-intensity rain or snow along slow-moving cold fronts; in contrast, summer rains are produced generally by short-duration, high-intensity thunderstorms, from purely convective buildup, or from convective cells developing along weak, fast-moving cold fronts. The summer convective storms produce about 80 percent of the annual rainfall, with over 50 percent of the annual total occurring in June, July, and August.[2]

The mean annual precipitation for the period 1956-65 was 11.18 inches with a standard deviation of 4.92 and a median of 10.96 inches. Such a deviation for 10 years of record shows the extreme variation in annual precipitation in the Southwest. Both indices of the average are below the long-term average of 14.01 inches recorded 35 miles west in Santa Rosa, N. Mex. The average precipitation for Santa Rosa for the 10-year period of this study is also about 3 inches higher than that on the watershed.[3]

The climatology of northeastern New Mexico pertaining to precipitation is well illustrated by the following descriptions of two storm periods on the Alamogordo Creek watershed. One storm represents a combination of a relatively fast moving weak front and strong convective heating. The other storm represents the slower moving stronger front, which resulted in rainfall over a relatively long period of time.

Storm of June 5, 1960

An occluded front moved across northeastern New Mexico and northwestern Texas on June 5. Weather Bureau stations recorded up to 0.75 inch of rain as this front passed. Since there was sufficient moist air aloft from the Gulf of Mexico, with strong convective heating in the afternoon, conditions were particularly good for thunderstorm activity. The resulting storm was localized, with its center over the experimental wastershed. Rainfall ranged from 0.15 inch to 4.09 inches, with five gages recording 4.00 inches of rain or more. At gage 34, 75 percent (3.09 inches) of the total precipitation of 4.09 inches fell in 15 minutes; 96 percent fell in the first hour.

Storm of July 3-8, 1960

The synoptic stiuation, at least partially responsible for these unprecedented rains, showed a moderately cold high pressure cell moving slowly down the eastern slope of the central Rocky Mountain range and thence eastward over the central plains. To the south, a weak low pressure center was located in northern Mexico. These systems moved very slowly, and the attending air circulation produced a flow of warm, moist air from the Gulf of Mexico northwestward for several days. As the moist air was lifted by the higher terrain and by the overrunning of the colder air to the west and north, widespread rains and considerable instability resulted.[4]

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Publications that present information from the rain gage network on Alamogordo Creek watershed are listed below. Conclusions and information derived from the rain gage network can be found in the abstracts listed with each publication reference.

(1) Drissel, J. C., and Osborn, H. B.
1968. Variability in rainfall producing runoff from a semiarid rangeland watershed, Alamogordo Creek, New Mexico. Jour. Hydrol. 6:194-201.

In eastern New Mexico, most of the winter precipitation occurs as low-intensity rain or snow along slow-moving cold fronts, whereas summer rains are produced by short-duration, high-intensity thunderstorms, from purely convective buildup, or from convective cells developing along weak, fast-moving cold fronts. These summer convective storms (May-October) produce about 80 percent of the annual rainfall.

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[2] Drissel, J. C., and Osborn, H. B. Variability in rainfall producing runoff from a semiarid rangeland watershed, Alamogordo Creek, New Mexico. Jour. Hydrol. 6: 194-201. 1968.

[3] Osborn, H. B., and Reynolds, J. N. Convective storm patterns in the southwestern United States. Internatl. Assoc. Sci. Hydrol. Bul. 3. 1963.

[4] von Escher, C. B. U.S. Weather Bur. Climatol. Data, New Mexico. 64(7). 1960.

Since runoff-producing precipitation on semiarid rangeland watersheds is of primary interest at the Southwest Watershed Research Center, the variability in rainfall affecting runoff has been analyzed for the Alamogordo Creek watershed. The 10-year mean, annual, seasonal, and monthly variations have been analyzed and compared with the long-term averages of nearby weather stations. The distribution and orographic effects have been discussed in detail. Variations in runoff yields were discussed and analyzed for the period of record.

(2) Hershfield, D. M.
1965. On the spacing of rain gages. Internatl. Assoc. Sci. Hydrol. Bul. 67.

The "key" gage theory was found to be applicable on the Alamogordo Creek watershed.

(3) Keppel, R. V.
1963. A record storm event on the Alamogordo Creek watershed in eastern New Mexico. Jour. Geophys. Res. 68(16):4877-4880.

Depths of precipitation for varying durations for a record storm are compared with similar Weather Bureau values for the 100-year storm. The expected 100-year point values were exceeded during this event for all durations up to 1 hour.

(4) Osborn, H. B., and Reynolds, W. N.
1963. Convective storm patterns, in the Southwestern United States, Internatl. Assoc. Sci. Hydrol. Bul. 8(3):71-83, 1963.

In the southwestern intermountain and high plains areas, precipitation is seasonal, with the major part of the rainfall occurring in the summer. Most winter precipitation occurs as low-intensity rain or snow along slow-moving cold fronts. Most summer precipitation occurs as short-duration, high-intensity thunderstorms from purely convective buildup or from convective cells developing along a weak fast-moving cold front. Almost all runoff occurs from the summer convective storms.

Since runoff-producing precipitation is of primary interest at the Southwest Watershed Research Center, the convective storms have been most thoroughly analyzed. Duration, intensity, areal extent, movement, character, and return frequencies for varying volumes and intensities of these convective storms are analyzed from records from dense networks of recording rain gages in four study areas in Arizona and New Mexico. The primary study areas are the 58-square-mile Walnut Gulch Experimental Watershed at Tombstone, Ariz., and the 67-square-mile Alamogordo Creek watershed near Santa Rosa, N. Mex. Three "record" storms of differing character occurring in 1960 and 1961 on Alamogordo Creek watershed and one record storm in 1961 on the Walnut Gulch watershed are analyzed and compared in detail.

(5) __________ and Keppel, R. V.
1966. Dense rain gage networks as a supplement to regional networks in semiarid regions. Symposium on Design of Hydro. Networks, Quebec, Canada, Internatl. Assoc. Hydrol. Bul. 68:675-687.

Because of their small size, widely scattered distribution, and short duration, convective thunderstorms typical of the Southwestern United States and many other semiarid regions can best be described by data gathered from dense recording rain gage networks on sufficiently large areas. Data are presented from two such networks—one of 60 recording gages located on a 67-square-mile area in eastern New Mexico, and one of 80 recording gages on 58 square miles in southeastern Arizona—showing depth-area and intensity-duration characteristics for convective thunderstorms. Comparisons are made between the frequency relationship computed from the long-time record at a point and that from a few years of dense network records based on the station-year concept. A storm on the eastern New Mexico area with exceptionally high intensities for durations up to 30 minutes is discussed.

(6) __________
1967. Variations in precipitation from thunderstorms in the Southwest. Proc. 5th Conf. on Severe Local Storms, Amer. Met. Soc., St. Louis, Mo., pp. 219-225.

Several storms are compared illustrating differences in depths, intensities, and areal extents of thunderstorm rainfall.

(7) Renard, K. G., Drissel, J. C., and Osborn, H. B.

(In press.) Flood peaks from a small southwest rangeland watershed. (Presented at Water Resources Meeting, Amer. Soc. Civ. Engin., New Orleans, La., Feb. 1969; scheduled for publication in March 1970, Jour. Hydrol. Div., ASCE.)

The five largest runoff events during the 14 years of record are compared and discussed in relation to precipitation differences. The annual peak discharge was fitted to several different frequency distributions and found to vary from 5,600 cfs to over 11,000 cfs for a 20-year recurrence interval.

CHAPTER 9.--COSHOCTON, OHIO

J. L. McGuinness[1]

A network of recording rain gages was established at the North Appalachian Experimental Watershed near Coshocton, Ohio, in the late 1930's and has been maintained with few changes to the present. Location of the rain gages is shown on figure 1, and the characteristics of the network gages are listed in table 1. Additional gages were operated during the first 3 or 4 years of the period of record (8). These were primarily standard gages. Due to the short period of operation, further details on these gages are not given.

Topography of the area varies from rolling to hilly. This site was chosen because it typifies much of the agricultural land in the unglaciated Allegheny Plateau, an area covering parts of southeastern Ohio, western Pennsylvania, western West Virginia, and a portion of eastern Kentucky.

The rain gage network was established to measure the temporal and areal variations in precipitation for 40 gaged experimental watersheds ranging from 0.6 to 17,500 acres. In addition, the network furnishes information which is useful in supplementing published generalized weather information. The close spacing of the research gages permits studies on a meso scale instead of the more prevalent macro scale studies.

Annual precipitation over the North Appalachian Experimental Watershed averages just over 37 inches (table 2). Winter precipitation, mainly due to cyclonic storms, is generally of low intensity but long duration (tables 2 and 3) and covers large areas (3). The average winter produces about 26 inches of snow. After melting, this is about 16 percent of the normal 16.81 inches of November to April precipitation. The ground is usually bare of snow (table 2) but snowmelt does make an occasional contribution to runoff.

Summer precipitation is characterized by convectional rains of high intensity but short duration (tables 2 and 3). These storms are erratic in their areal distribution, but they tend to cover smaller areas than the winter storms (3).

Precipitation characteristics influence the timing of runoff from the experimental watersheds. Small areas--under 10 acres--have most of their runoff volume in late spring and early summer in response to high rainfall intensities at that time of year. Areas of 1,000 acres or more have the bulk of their runoff in late winter or early spring. Flows in this season are in response to moderate precipitation on well-saturated land areas. Runoff amount from any one field is small, but all fields in the larger watershed contribute runoff. This is in contrast to the summer runoff events where the storm usually covers only part of the larger watersheds. Of course, other factors such as geology also have an influence on the flow regimes.

Many workers have utilized the data obtained from the research network. Riesbol (15, 16) found exposure to the wind to be the most important factor affecting rain gage catch. Schiff (17) used 6 years of data from the research network to establish five classes of storms depending on the pattern and intensity of the rains and used this classification in a runoff prediction system (16). Dreibelbis (2) showed a correlation between soil loss and amounts of rain falling at high intensities. McGuinness and Brakensiek (10) used precipitation data to illustrate a technique for determining representativeness of a sampling period and Brakensiek (1) and McGuinness and Brakensiek (11) used rainfall intensity data to illustrate frequency curve fitting techniques. Harrold (4) discussed the relationship of precipitation to the other elements of the hydrologic cycle, and Harrold et al. (5) gave a detailed description of the precipitation climatology of the station. Ricca et al. (14) showed that precipitation during the 1939-66 study period at Coshocton was entirely representative of the long-term climate of the area.

McGuinness (8) used short-term standard gage data to supplement the recording gage results in a study of the accuracy of estimating watershed mean rainfall. The average error of determination was related to rain amount and gaging ratio as well as geographic location. Shanholtz and Dickerson (19) related rainfall characteristics such as intensity, duration, and pattern of rain to runoff. McGuinness (9) showed that a recording rain gage tends to

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[1] Statistician, North Appalachian Experimental Watershed, Coshocton, Ohio 43812.

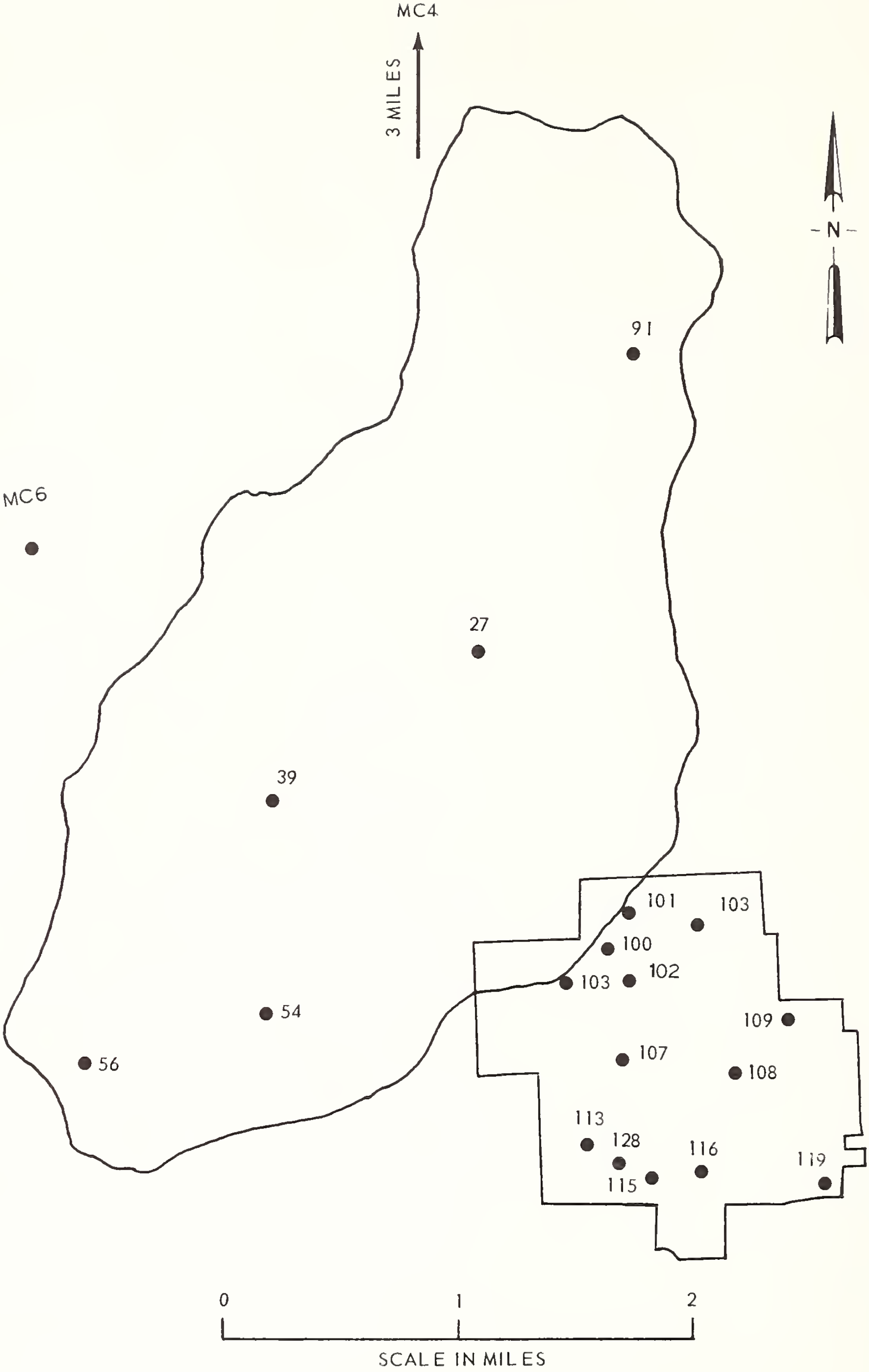

Figure 1.–Rain gage locations at North Appalachian Experimental Watershed near Coshocton, Ohio

Table 1.—Characteristics of rain gage network at Coshocton, Ohio[1]

Gage No.	Chart scale hours	Record began[2]	Elevation above mean sea level	Data on cards[3]
	Hour	*Date*	*Feet*	*Date*
MC-4	24	8-54	900	54-66
MC-6	24	8-54	835	54-66
27	24	5-37	910	38-66
39	24	1-43	850	43-66
54	24	7-37	850	39-66
56	24	1-37	810	39-66
91	24	7-37	985	45-66
100	12	9-37	1,220	37-68
Y101	6	5-37	1,200	-
Y102	6	6-37	1,193	37-68
Y103	6	4-39	1,130	-
103	12	9-37	1,200	38-68
107	12	1-39	1,150	-
108	12	10-37	1,040	-
109	12	9-37	1,165	-
113	12	1-40	1,149	40-66
115	12	12-39	1,147	-
116	12	1-38	1,093	-
119	12	1-38	915	-
128	12	1-43	1,110	-

[1] Gages are all the weighing-recording type.
[2] All records continuous to present time.
[3] All data are in breakpoint tabulations.

Table 2.—Average monthly values of various precipitation characteristics at Coshocton, Ohio, 1937-68

Month	Precipitation	Total snowfall	Days with snow cover	Individual storms	Precipitation per storm	Duration of storm
	Inches	*Inches*	*No.*	*No.*	*Inches*	*Minutes*
Jan.	2.86	7.6	13	12	0.23	321
Feb.	2.30	7.1	10	12	.19	267
Mar.	3.47	3.6	5	15	.21	254
Apr.	3.51	.1	0	16	.20	208
May	3.92	–	–	17	.22	167
June	4.34	–	–	15	.29	119
July	4.40	–	–	14	.31	113
Aug.	2.87	–	–	11	.27	116
Sept.	2.58	–	–	10	.25	155
Oct.	2.16	–	–	10	.21	223
Nov.	2.41	1.4	1	12	.19	258
Dec.	2.26	6.4	10	11	.19	303
Totals	37.08	26.2	39	155	–	–

Table 3.—Average rainfall amounts falling at rates above selected intensities, 1937-68

[T - trace (less than 0.005 inches)]

Average intensity (In./hr.)	Amounts of rain that fell at rates higher than those in first column												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	Inches												
0	2.86	2.30	3.47	3.51	3.92	4.34	4.40	2.87	2.58	2.16	2.41	2.26	37.08
.3	.13	.11	.38	.49	1.18	2.15	2.35	1.38	.90	.36	.18	.10	9.71
.5	.07	.07	.25	.34	.91	1.79	1.96	1.12	.65	.25	.11	.05	7.57
1.0	.03	.04	.12	.21	.55	1.17	1.24	.68	.36	.13	.06	.02	4.61
2.0	.01	.02	.04	.07	.24	.54	.50	.27	.12	.05	.02	T	1.88
4.0	T	T	T	.01	.05	.14	.09	.05	.01	.01	.01	0	.37

undercatch as compared with lysimeter measurements of precipitation. McGuinness and Vaughan (13) showed a seasonal bias in the catch of several widely used gage types. Hershfield (6, 7) used Coshocton data in his studies on the properties of rain gage networks.

One outgrowth of the studies on the research network has been a realization that the size of the network area was too small to provide definitive information on storm morphology. This led to the establishment of a dense network of tube-type gages in a 1,500 square-mile area north of the North Appalachian Experimental Watershed (12). Data from this network are useful in characterizing the severe local storms of the area. The data may also lead to a reappraisal of design factors; one area has experienced three storms well over the expected 100-year recurrence value within a 7-year period!

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CHAPTER 10.--CHICKASHA, OKLA.

Arlin D. Nicks[1]

In 1960 comprehensive research was initiated on the Washita River watershed in Oklahoma to determine the changes that may take place in the flood flows, water and sediment yields, and channel characteristics of the main stem of the river as a result of the installation of upstream conservation works. A 1,130-square-mile area contributing to the central reach of the river was selected for intensive investigation because conservation works had not yet been constructed but were planned for the near future. An important goal of the studies was a reliable assessment of the precipitation input to the area. To provide for this assessment, a rain gage network was designed and installed on the study reach.

In addition to the major research objective of measuring precipitation on the experimental area, it was also necessary to assess the rainfall on smaller units of study such as the tributaries to the main stem. Other specific objectives pertinent to these units are (1) to develop basic information on amounts, duration, areal and seasonal distribution, storm paths, and other characteristics of precipitation affected by geographic location, topography, and other factors; (2) to determine and evaluate precipitation parameters useful in estimating runoff; and (3) to relate point precipitation measurements to mean precipitation on various size watersheds.

The rain gage network shown in figure 1, consists of a uniform network of recording gages spaced on a 3- by 3-mile grid, which provides one gage per 9 square miles. The lines of the grid are oriented in a north-south direction. The basic network includes 168 gages.

Additional gages have been added to the network as the project expanded to its full scope. In 1962, seven additional gages were installed on small watershed study areas. Nine additional gages operated by the National Severe Storms Laboratory, ESSA, were also included in the records in 1962 (gages 176 through 184). During the period from 1965 to 1967, 44 gages were added in five different areas within the network to provide detailed precipitation data for other small watershed studies. This brought the total number of gages in the network to 228. Table 1 lists the period of record, recording time scale, latitude, longitude, and elevation for each gage.

TOPOGRAPHY

The network lies between latitudes 34° 45′ to 35° 45′ and longitudes 97° 30′ to 98° 30′. The topography of this area is characterized by rolling plains cut by deeply eroded valleys. Maximum relief is approximately 450 feet occurring in the northwest quadrant of the network between gages 13 and 104. The predominant topographic features of the area are the Washita River and associated flood plains which comprise 10 percent of the area.

DATA PROCESSING

Charts from the 228 recording rain gages are processed by two methods. In the first method, after the charts are collected from the field, the dates and beginning and ending times of precipitation events and time and gage height corrections are entered on the charts. At the same time, daily precipitation amounts–24-hour totals ending at midnight–are tabulated. These values are hand punched on cards for further processing by computer. This procedure accounts for all of the hand processing of data. In the second method of data processing, the precipitation chart traces are converted to digital form by an automatic analog-to-digital converter-chart reading system. The system

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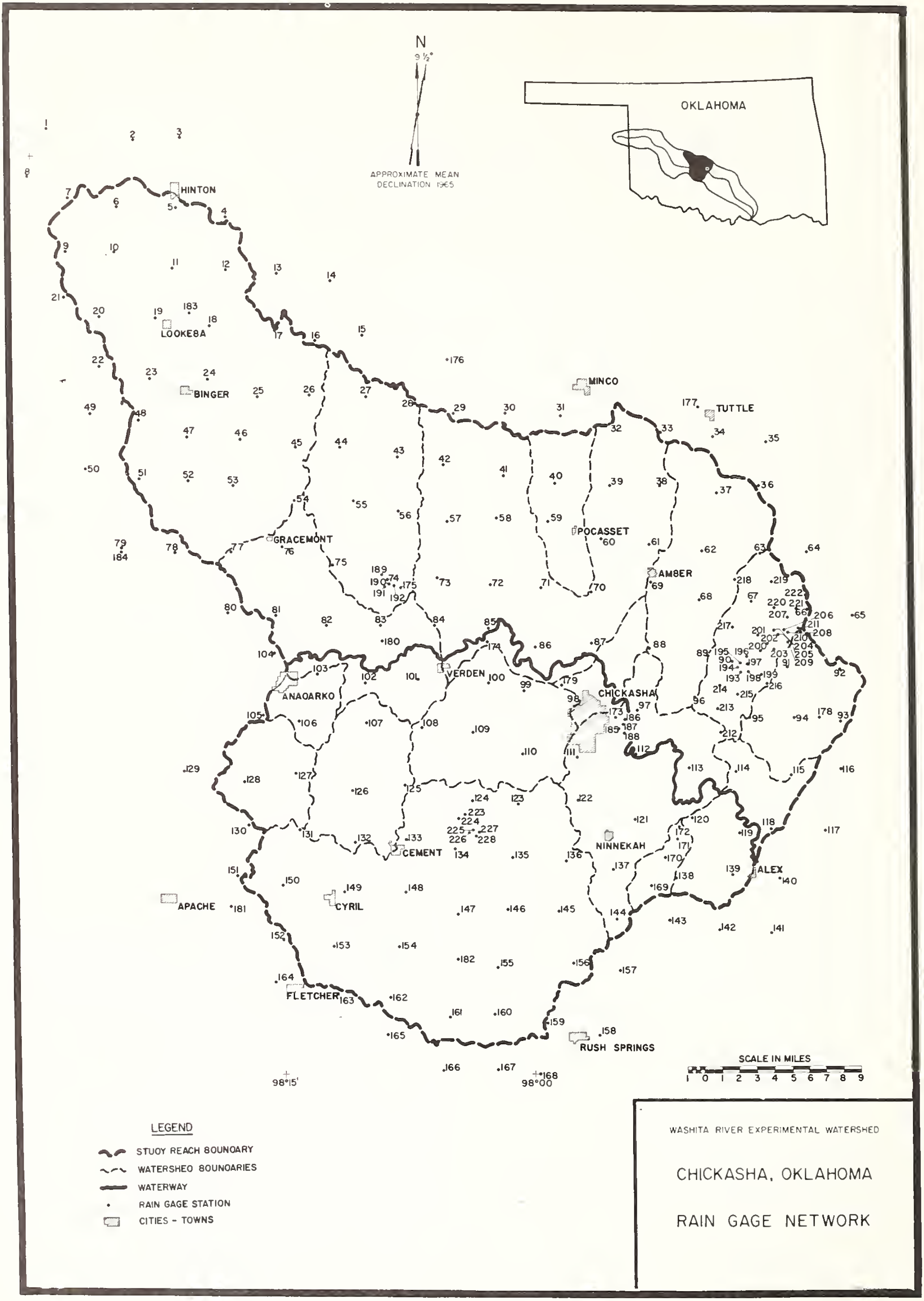


Figure 1.–Rain gage network, Washita River Experimental Watershed, Chickasha, Okla.

Table 1.—Rain gage network station data, Chickasha, Okla.

Gage No.[1]	Installation date[2]	Latitude			Longitude			Elevation
		Degrees	*Minutes*	*Seconds*	*Degrees*	*Minutes*	*Seconds*	*Feet*
1		35	31	21	98	28	57	1,540
2		35	30	53	98	23	43	1,580
3		35	30	45	98	21	00	1,610
4		35	26	59	98	18	10	1,640
5		35	27	25	98	21	20	1,580
6		35	27	28	98	24	44	1,640
7		35	27	53	98	27	46	1,650
8		35	28	57	98	30	04	1,640
9		35	25	14	98	27	53	1,640
10		35	25	15	98	24	53	1,500
11		35	24	23	98	21	31	1,440
12		35	24	22	98	18	15	1,630
13		35	24	17	98	15	14	1,660
14		35	24	00	98	12	08	1,540
15		35	21	18	98	10	06	1,540
16		35	20	56	98	12	52	1,590
17		35	21	34	98	15	12	1,580
18		35	21	45	98	19	07	1,520
19		35	21	59	98	22	33	1,460
20		35	22	00	98	25	47	1,610
21		35	23	05	98	27	54	1,650
22		35	19	41	98	25	46	1,510
23		35	19	09	98	22	45	1,990
24		35	19	03	98	19	25	1,440
25[3]		35	18	17	98	16	16	1,400
26		35	18	32	98	13	17	1,360
27		35	18	06	98	10	00	1,440
28		35	17	47	98	06	54	1,520
29		35	17	31	98	04	33	1,520
30		35	17	30	98	01	19	1,350
31		35	17	26	97	57	41	1,350
32		35	16	52	97	55	06	1,420
33		35	16	33	97	52	02	1,340
34		35	16	16	97	48	47	1,330
35		35	15	57	97	45	34	1,300
36		35	13	57	97	46	03	1,400
37		35	13	25	97	48	44	1,320
38		35	13	57	97	52	03	1,240
39		35	13	55	97	55	06	1,150
40		35	13	58	97	58	22	1,250
41		35	14	24	98	01	28	1,240
42		35	14	52	98	05	13	1,350
43		35	15	10	98	07	57	1,370
44		35	15	45	98	11	24	1,300
45		. . . .	do.	. . . .	98	14	04	1,460
46		35	15	54	98	17	20	1,360
47		35	16	10	98	20	31	1,420
48		35	17	03	98	23	38	1,540
49		35	17	25	98	26	27	1,450
50		35	14	40	98	26	47	1,450
51		35	14	12	98	23	39	1,510
52		35	14	02	98	20	30	1,430
53		35	13	56	98	17	49	1,430
54		35	13	08	98	14	08	1,490
55		. . . .	do.	. . . .	98	10	38	1,280
56		35	12	38	98	07	48	1,280
57		35	12	13	98	05	02	1,210
58		35	12	14	98	01	58	1,210
59[2]		35	12	13	97	58	32	1,230
60		35	11	19	97	55	29	1,140
61		35	11	08	97	52	53	1,230
62		35	10	41	97	49	43	1,200
63		35	10	30	97	46	04	1,370
64[2]		35	10	35	97	43	20	1,280

See footnotes at end of table.

Table 1.—Rain gage network station data, Chickasha, Okla.—Continued

Gage No.[1]	Installation date[2]	Latitude			Longitude			Elevation
		Degrees	*Minutes*	*Seconds*	*Degrees*	*Minutes*	*Seconds*	*Feet*
65		36	07	28	97	40	27	1,310
66		35	07	44	97	43	20	1,360
67		35	08	05	97	46	35	1,280
68		35	08	10	97	49	45	1,220
69		35	08	56	97	52	52	1,220
70		35	08	43	97	56	12	1,140
71		35	08	49	97	59	18	1,200
72		35	08	55	98	02	20	1,140
73		35	09	23	98	05	28	1,240
74		35	09	21	98	08	36	1,260
75[2]		35	09	58	96	11	48	1,380
76		35	10	39	98	14	56	1,220
77		35	10	36	98	18	05	1,400
78		35	10	30	98	21	17	1,440
79		35	10	46	98	24	26	1,440
80		35	07	49	98	18	07	1,380
81		35	07	41	98	15	18	1,360
82		35	07	02	98	12	12	1,180
83		35	07	01	98	09	01	1,220
84		.... do.			98	06	00	1,190
85		35	06	53	98	02	31	1,120
86		35	06	06	97	59	38	1,130
87		35	06	07	97	56	08	1,150
88		35	06	01	97	52	52	1,220
89		35	05	40	97	49	13	1,200
90		35	05	17	97	47	51	1,250
91		35	05	05	97	44	26	1,250
92		35	05	02	97	41	16	1,310
93		35	02	21	97	41	18	1,300
94		35	02	37	97	44	06	1,250
95		.... do.			97	46	48	1,250
96		35	03	33	97	50	01	1,150
97		35	02	47	97	53	33	1,110
98		35	03	22	97	57	05	1,090
99		35	03	55	98	00	19	1,110
100		35	04	20	98	02	26	1,140
101		35	04	32	98	06	45	1,200
102		35	04	18	98	09	49	1,180
103		35	04	46	98	12	52	1,180
104		35	05	42	98	15	17	1,190
105		35	02	37	98	16	04	1,310
106		35	02	22	98	13	59	1,220
107		35	02	17	98	09	50	1,240
108		35	01	51	98	06	36	1,350
109		35	01	45	98	03	27	1,230
110		35	00	50	98	00	22	1,240
111		35	00	45	97	57	09	1,210
112		35	00	55	97	53	41	1,050
113		35	00	04	97	50	34	1,100
114		35	00	03	97	47	38	1,150
115		34	59	44	97	44	29	1,150
116		35	00	05	97	41	27	1,160
117		34	57	05	97	42	22	1,040
118		34	57	01	97	45	32	1,100
119		34	56	49	97	47	36	1,040
120		34	57	36	97	50	18	1,060
121		34	57	31	97	53	55	1,120
122		34	58	39	97	57	08	1,170
123		34	58	16	98	00	48	1,220
124		34	58	26	98	03	28	1,280
125		34	59	08	98	07	39	1,380

See footnotes at end of table.

Table 1.–Rain gage network station data, Chickasha, Okla.–Continued

Gage No.[1]	Installation date[2]	Latitude			Longitude			Elevation
		Degrees	*Minutes*	*Seconds*	*Degrees*	*Minutes*	*Seconds*	*Feet*
126		34	59	00	98	18	49	1340
127[2]		34	59	46	98	14	01	1380
128		34	59	23	98	17	12	1340
129		34	59	59	98	20	51	1360
130		34	57	23	98	17	05	1410
131		34	56	53	98	13	59	1490
132		34	56	30	98	10	42	1400
133		34	56	31	98	07	30	1400
134		34	56	06	98	04	31	1260
135		34	55	39	98	01	10	1180
136[2]		34	55	37	97	58	01	1200
137		34	54	57	97	55	02	1140
138		34	54	46	97	51	21	1170
139		34	54	48	97	48	01	1060
140[2]		34	54	40	97	44	55	1040
141		34	51	55	97	45	31	1140
142		34	52	03	97	48	40	1000
143		34	52	34	97	51	49	1160
144		34	52	47	97	54	59	1260
145		34	53	03	97	58	28	1220
146		34	53	09	98	01	22	1180
147		34	53	01	98	04	30	1410
148		34	54	03	98	07	40	1400
149		34	54	05	98	11	20	1360
150		34	54	21	98	15	02	1400
151		34	54	48	98	17	40	1450
152[2]		34	51	39	98	15	02	1360
153		34	51	29	98	11	54	1340
154		34	51	19	98	08	01	1320
155		34	50	26	98	02	10	1290
156		34	50	33	97	57	28	1310
157		34	50	11	97	54	48	1250
158		34	47	00	97	55	55	1340
159		34	47	35	97	59	03	1420
160		34	48	05	98	02	12	1350
161		34	47	51	98	04	59	1400
162		34	48	48	98	08	30	1310
163		34	49	03	98	11	42	1340
164		34	49	34	98	15	49	1310
165		34	46	58	98	08	45	1300
166		34	45	14	98	05	21	1280
167		34	45	16	98	02	10	1300
168		34	45	14	97	59	38	1310
169	3-01-62	34	54	16	97	52	53	1160
170	3-01-62	34	55	40	97	51	53	1160
171	3-01-62	34	56	33	97	51	14	1160
172[4]	3-01-62	34	57	12	97	51	00	1100
173[4]		35	02	45	97	54	38	1090
174[4]	3-01-62	35	06	16	98	02	33	1120
175		35	08	47	98	07	42	1180
176	1-01-62	35	20	04	98	05	03	1440
177	1-01-62	35	17	33	97	49	45	1300
178	1-01-62	35	02	36	97	42	28	1160
179	1-01-62	35	04	13	97	58	11	1100
180	1-01-62	35	06	15	98	09	16	1170
181	1-01-62	34	53	21	98	18	12	1410
182	1-01-62	34	50	42	98	04	24	1210
183	1-01-63	35	22	23	98	20	27	1430
184	1-01-63	35	10	42	98	24	28	1440
185	1-01-65	35	02	02	97	54	45	1080
186	2-01-66	35	02	25	97	54	22	1080

See footnotes at end of table.

Table 1.—Rain gage network station data, Chickasha, Okla.—Continued

Gage No.[1]	Installation date[2]	Latitude			Longitude			Elevation
		Degrees	*Minutes*	*Seconds*	*Degrees*	*Minutes*	*Seconds*	*Feet*
187	2-01-66	35	02	18	97	54	34	1080
188	2-01-66	35	01	53	97	54	28	1080
189	2-01-66	35	09	26	98	08	42	1270
190	2-01-66	35	09	16	98	08	32	1260
191	2-01-66	35	09	09	98	08	41	1210
192	2-01-66	35	09	09	98	08	24	1230
193	7-01-66	35	04	56	97	47	26	1200
194	7-01-66	35	05	06	97	47	37	1230
195	7-01-66	35	05	21	97	47	29	1230
196[3]	7-01-66	35	05	32	97	47	15	1260
197	7-01-66	35	05	16	97	47	13	1240
198	7-01-66	35	05	04	97	47	11	1190
199	10-01-66	35	04	54	97	46	29	1150
200	10-01-66	35	05	38	97	46	34	1220
201	10-01-66	35	06	21	97	46	51	1280
202	10-01-66	35	05	43	97	46	15	1240
203	10-01-66	do.			97	45	43	1200
204	10-01-66	35	06	41	97	45	52	1300
205	10-01-66	35	06	15	97	45	31	1270
206	9-27-66	35	06	51	97	45	00	1270
207	9-27-66	35	07	27	97	44	30	1320
208	9-27-66	35	06	40	97	44	27	1300
209	9-27-66	35	06	20	97	44	28	1270
210	8-31-66	35	06	44	97	43	46	1340
211	9-27-66	35	06	59	97	43	53	1340
212	10-01-66	35	01	47	97	48	40	1160
213	8-31-66	35	03	06	97	48	42	1090
214	10-01-66	35	04	16	97	48	40	1120
215	10-01-66	35	03	11	97	47	36	1120
216	8-31-66	35	04	00	97	45	58	1240
217	9-27-66	35	07	01	97	47	46	1210
218	9-27-66	35	09	17	97	47	38	1300
219	9-27-66	35	09	11	97	45	59	1330
220	9-27-66	35	07	53	97	45	24	1270
221	9-27-66	do			97	43	57	1370
222	9-27-66	35	08	29	97	43	22	1390
223	11-01-68	34	57	49	98	04	17	1240
224	11-01-68	34	57	37	98	04	28	1340
225	11-01-68	34	57	03	98	03	28	1270
226	11-01-68	34	56	58	98	03	45	1340
227	11-01-68	34	56	56	98	03	14	1260
228	11-01-68	34	56	41	98	03	23	1320

[1] All gages are the weighing-recording type with a 24-hr. time scale, except as footnoted.

[2] Gages were installed 10-1-61 unless otherwise noted.

[3] Time scale = 192 hrs.

[4] Time scale = 12 hrs. for gages 172, 173, and 176 thru 228.

automatically punches the data necessary for computer computation of intensity by scanning the chart trace and punching on cards time and gage height values at points along the trace where there is a change or break in slope.

The tabulation of daily amounts is current. Daily values from each gage for the period of record have been placed on punchcards. These values have been processed by computer to obtain daily, monthly, and annual totals on a tabular listing form. Also, mean daily precipitation for all drainage areas above runoff stations for all years of record have been computed from the daily totals. These data are also in tabular form and on punchcards. Breakpoint intensity data are listed in tabular form and are recorded on cards for all storms of 1962 and 1963; 24, of 1964; 19, of 1965; 19 of 1966; 24, of 1967; 37, of 1968; and 22, of 1969. Precipitation intensity data for most major runoff-producing storms have been processed.

PRECIPITATION CLIMATOLOGY

The network area is in a region of moist to dry subhumid climate. Normal annual precipitation according to U.S. Weather Bureau data varies from 33 inches on the east to 28 inches on the west edge of the network. The normal for Chickasha, near the center of the area, is 31.60 inches. Annual precipitation totals at points in the watershed have been as large as 47 inches and as small as 16 inches. Distribution of precipitation throughout the year is bimodal with peaks occurring in May and September. About 98 percent of the yearly precipitation occurs as rainfall with the remaining 2 percent occurring as sleet and snow. Snow falls on the average of 5 days during the period from November through March and is not a factor contributing to flooding. Flooding can occur at any time during the year, but it is most frequent during late spring and early fall and is associated with thunderstorm rainfall.

During 7 years of network operation, some interesting observations of precipitation characteristics have been made. The average annual precipitation determined from the network measurements from 1962 to 1968 was 26.39 inches. The areal distribution is shown in figure 2. During this 84-month period, 71 months have been below

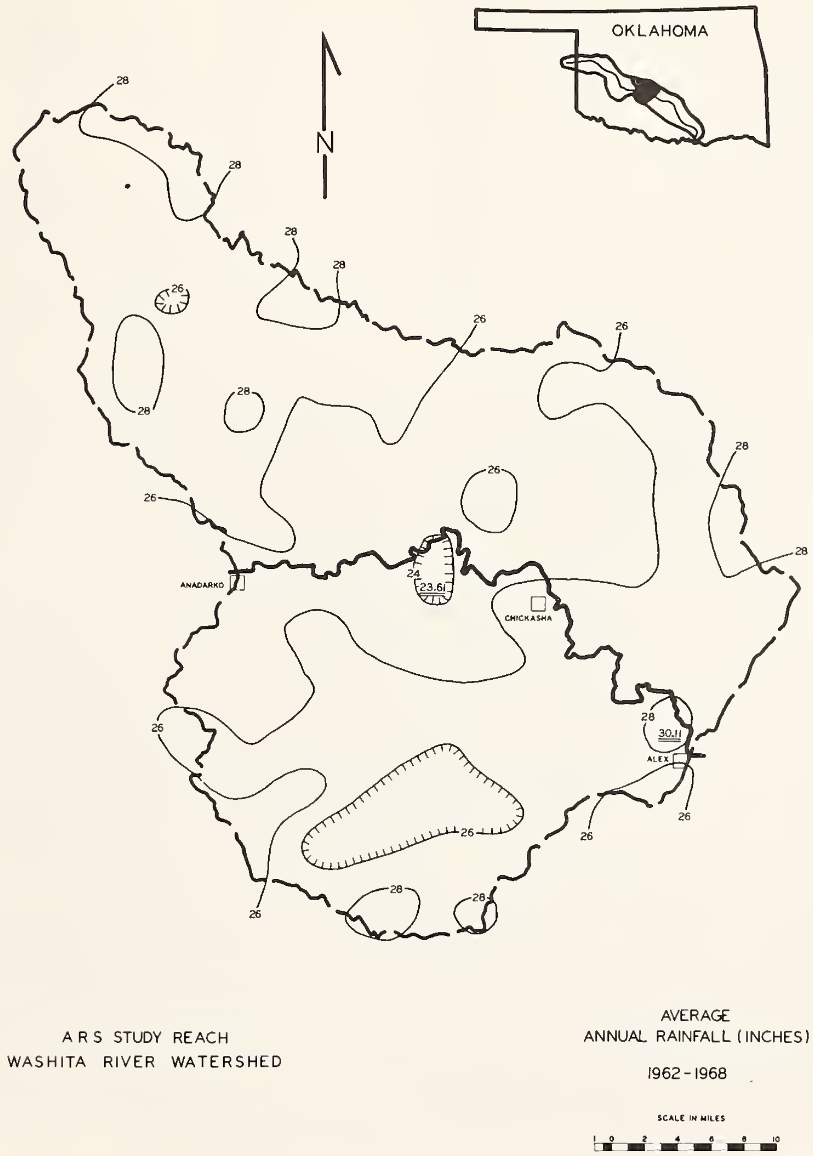


Figure 2.—Average annual rainfall (inches), 1962-68, Washita River watershed.

normal in rainfall. Only 1 year, 1968, was above normal. The maximum precipitation at a rain gage station this year was 42.84 inches and the minimum was 26.89 inches, a difference of 15.95 inches occurring at stations 20 miles apart. Similar variations in annual point measurement have been observed each year. Difference between the yearly network extremes has averaged 15 inches. The distance between the two stations having the most and the least rainfall averaged 31 miles. Results of a study published in 1966 (7) indicate that such variations would not be expected from the usual climatological station spacing.

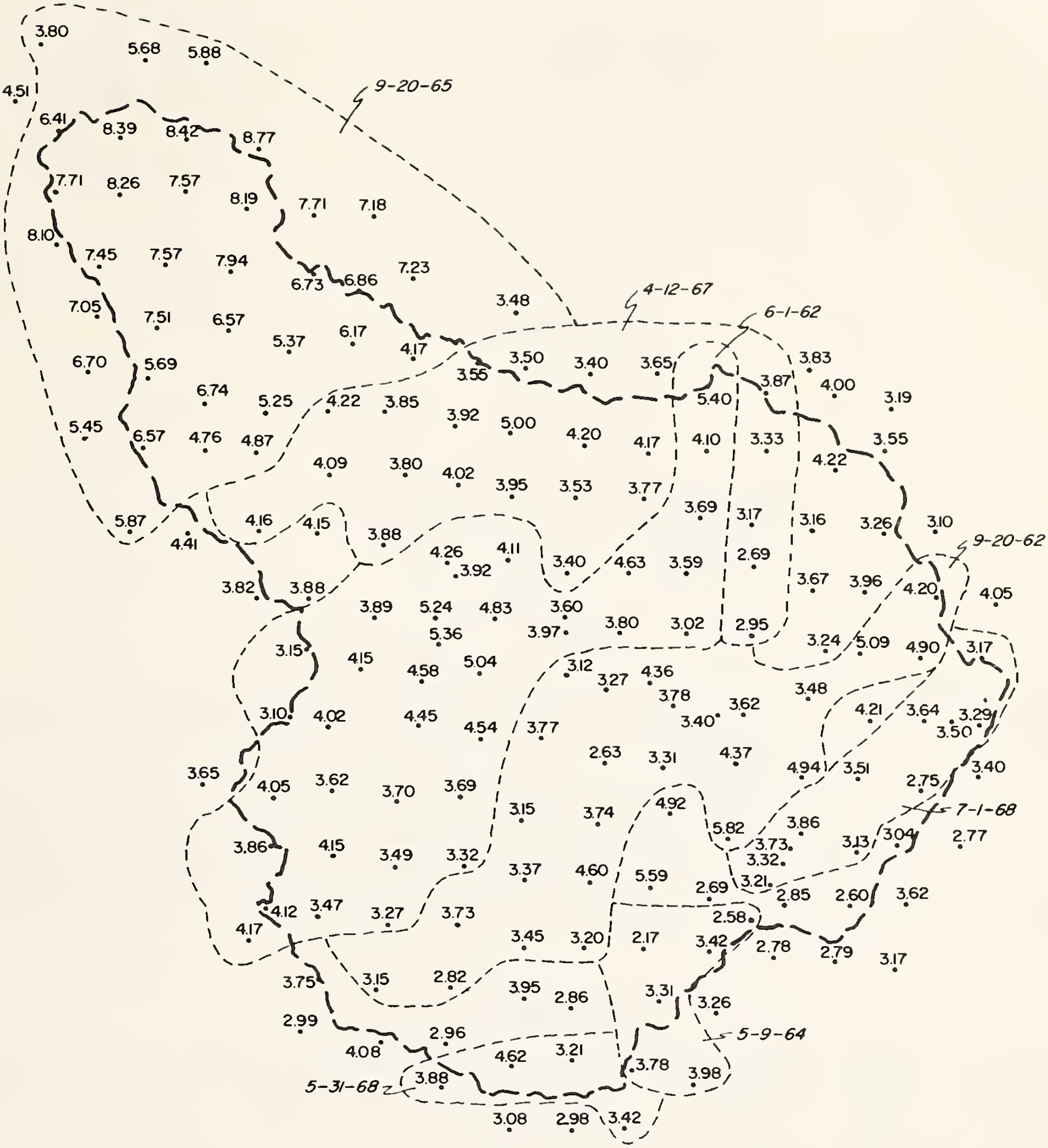
Despite the below-normal annual precipitation during the period of record, several storms have produced large point amounts (1). Some of the larger storms are listed in table 2. The average return periods indicated for these storms are based on the data given in U.S. Weather Bureau Technical Paper 40. Return periods exceeding 100 years have been experienced at 13 percent of the stations. However, for 79 percent of the network stations, the maximum recorded storm rainfall has been less than the 10-year storm, for 5 percent more than 10 but less than 50 years, and for 3 percent more than 50 but less than 100 years. Figure 3 shows the maximum recorded 1-day rainfall for each station in the network.

Table 2.–Summary of maximum storm rainfall, Washita River watershed

Date	Amount	Duration	Average return period
	Inches	*Hours*	*Years*
6/1/62	5.40	12	15
9/3/62	6.14	6	75
9/20/62	5.82	10	25
6/23/63	5.76	8	30
9/16/63	5.87	16	15
5/9/64	4.08	3	20
5/10/64	5.16	12	10
6/21/65	6.00	4	>100
9/20/65	8.77	5	>100
6/8/66	3.72	2	20
8/11/66	3.62	4	5
4/12/67	4.34	6	10
8/17/67	3.47	4	5

Storm rainfall differences have also shown a high degree of variability. Differences of 4.5 inches in 6 miles have been observed in local as well as widespread storms. Yearly occurrence of such variation appears to be characteristic of rainfall for this region. Because of such large variation, a study was made to assess the adequacy of the network gages to measure daily rainfall (6). The results indicate that at the 5-percent level, the average daily rainfall for the area computed from five gages was significantly different from that computed from 158 gages. At a density of 10 equally spaced gages over the watershed, there was no significant difference in the amount of rainfall, indicating that areal estimates of the daily rainfall for the 1,130-square-mile area determined by 158 gages could be obtained from a network that is considerably less dense. However, when the same analysis was applied to subdrainage areas within the 1,130-square-mile area, any reduction in the number of gages resulted in a poorer definition of the rainfall pattern and areal mean rainfall estimates.

On September 20, 1965, the largest precipitation event recorded by the network occurred in the northwest section of the study reach on Sugar Creek watershed. This storm produced a maximum point rainfall of 8.77 inches in 5 hours. Approximately 10,000 acres of cropland and timberland along Sugar Creek and the Washita River flood plains were flooded (2). The pattern of rainfall from this storm (fig. 4) shows a uniform increase from the 2-inch isohyetal near Gracemont to an 8-inch value near Hinton. However, this storm was composed of several small intense cells of rainfall traversing the watershed at speeds up to 30 miles per hour. Figure 5 shows the relative size and shape of several of these cells as depicted by isohyetal plottings. Such cellular structures appear to be a characteristic of the frontal-type thunderstorms that occur in this climatic region.



MAXIMUM DAILY RAINFALL
1962-1968

Figure 3.—Maximum daily rainfall, in inches for the Washita River watershed, 1962-68.

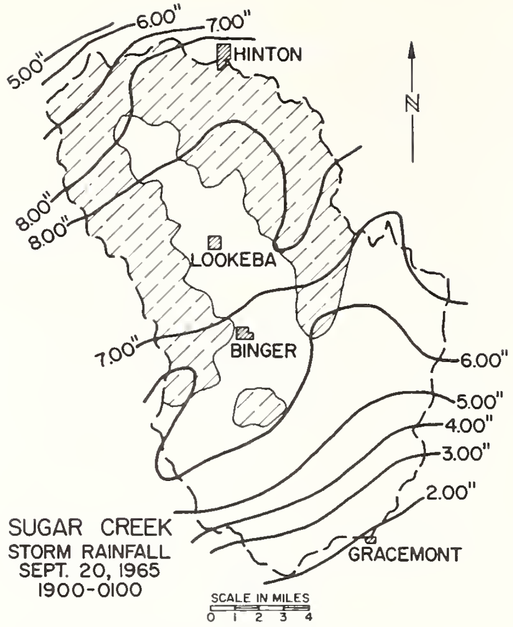


Figure 4.—Sugar Creek storm rainfall, Sept. 20, 1965.

Rain gage network measurements have been compared to rainfall estimates made by weather radar (4). Using the WSR-57 radar at the National Severe Storms Laboratory at Norman, Okla., McCallister et al. (5) showed close agreement between a storm pattern measured by the network and that measured by radar technique. Wilson (8) compared six storms from the rain gage network with the radar estimates and concluded that four of the storms closely approximated existing radar-rainfall relationships. Wilson also concluded that the sample studied was too small to specify the success of radar-rainfall estimates for all Oklahoma thunderstorms. Hudlow (3) found that despite large discrepancies between the amount of rainfall measured by the network and that measured by radar, the radar accurately located the rainfall. This finding was confirmed by correlating the occurrence of runoff from the affected area with the indicated rainfall.

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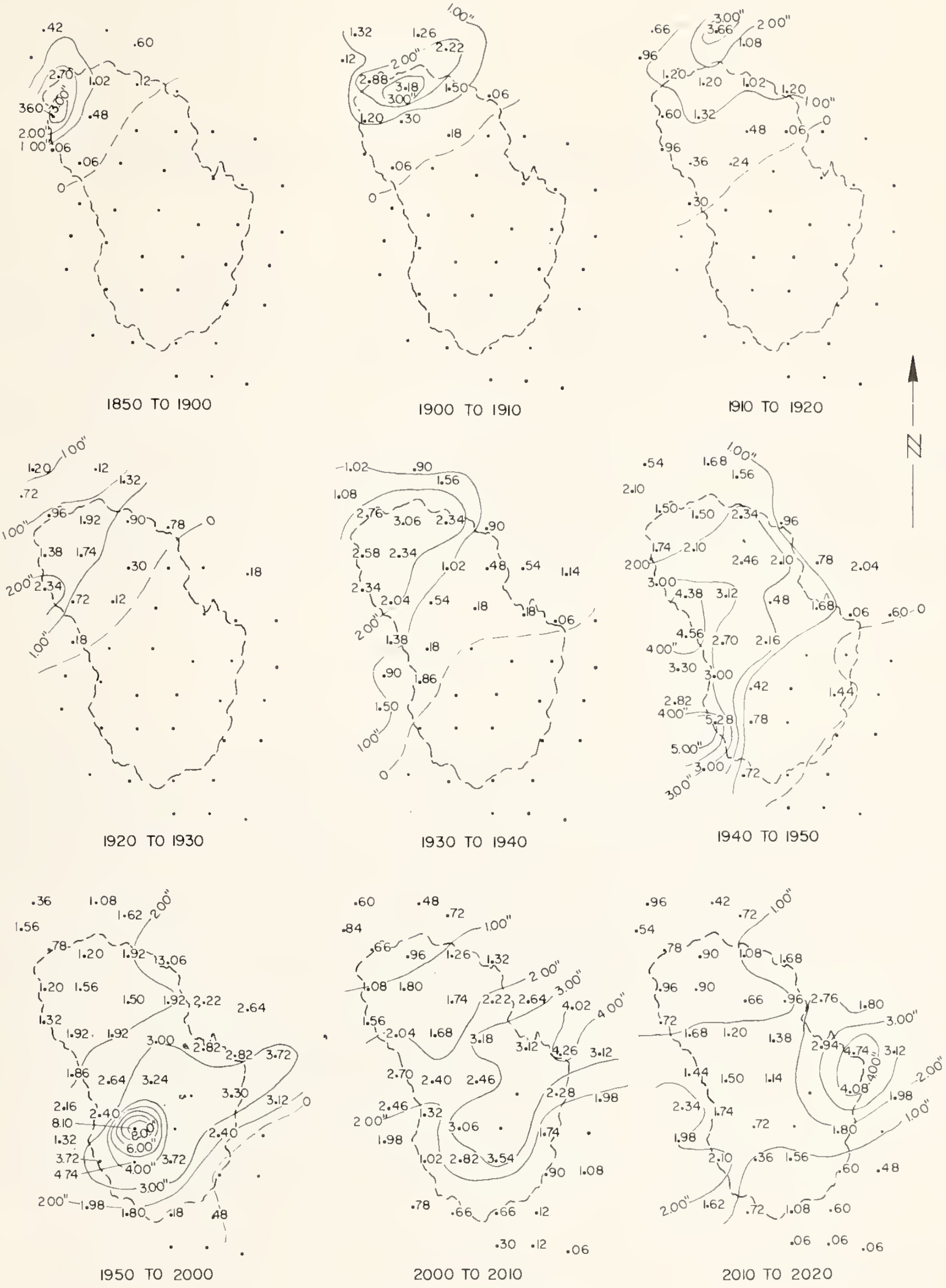

SUGAR CREEK WATERSHED
10 MINUTE RAINFALL INTENSITY (INCHES PER HOUR)
SEPTEMBER 20, 1965

Figure 5.–Sugar Creek 10-minute rainfall intensity, Sept. 20, 1965.

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1966. Variations of rainfall over a large gaged area. Amer. Soc. Agr. Engin. Trans. 9(3): 437-439.

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CHAPTER 11.--KLINGERSTOWN, PA.

Jan C. Carr[1]

The Northeast Watershed Research Center, one of six Regional Watershed Research Centers in the Agricultural Research Service's watershed research program, was established in 1966. The purpose of this Center is to study the interaction of land and water resources in an agricultural environment with major research areas in engineering hydrology and water quality. The principal unit of research is the agricultural watershed in which outputs can be balanced against inputs.

The 162-square-mile Mahantango watershed has been instrumented with a network of 43 rain gages and seven stream gaging stations. Other data for selective research projects are being collected, such as pan evaporation, wind movement, temperature and humidity, soil moisture, radiation, snow depth, and ground water levels.

Goals of precipitation research are to characterize the areal and temporal distribution of precipitation with respect to local topography and the larger atmospheric conditions. Such information is necessary input for hydrologic studies and simulation models.

TOPOGRAPHY

The research watershed is located in the nonglaciated section of the North Appalachian Ridge and Valley Region of eastern Pennsylvania. The watershed is an elongated area of about 162 square miles; the long axis is 33 miles and lies in an east-west direction (fig. 1). The watershed is divided along its central axis and throughout almost its entire length by Mahantango Mountain. This mountain is typical of the mountains in this area which form long continuous ridges of fairly uniform elevations around 1,100 to 1,500 feet. These ridges are separated by quite narrow and intensively cultivated basins with rolling terrain of elevations between 400 and 800 feet. Basin widths vary between 1 and 5 miles. The northern watershed basin is drained by the East Mahantango Creek, which flows into the Susquehanna River some 30 miles upstream from Harrisburg, Pa. The southeastern and southwestern basins are drained by Pine Creek and Deep Creek, respectively; each flows into East Mahantango Creek after passing through very narrow water gaps. Along the southern boundary of the southeastern basin, the Rausch Creek area, which is extensively stripmined of coal, drains into Pine Creek through another water gap. These water gaps are a typical feature of the North Appalachian Ridge and Valley Region.

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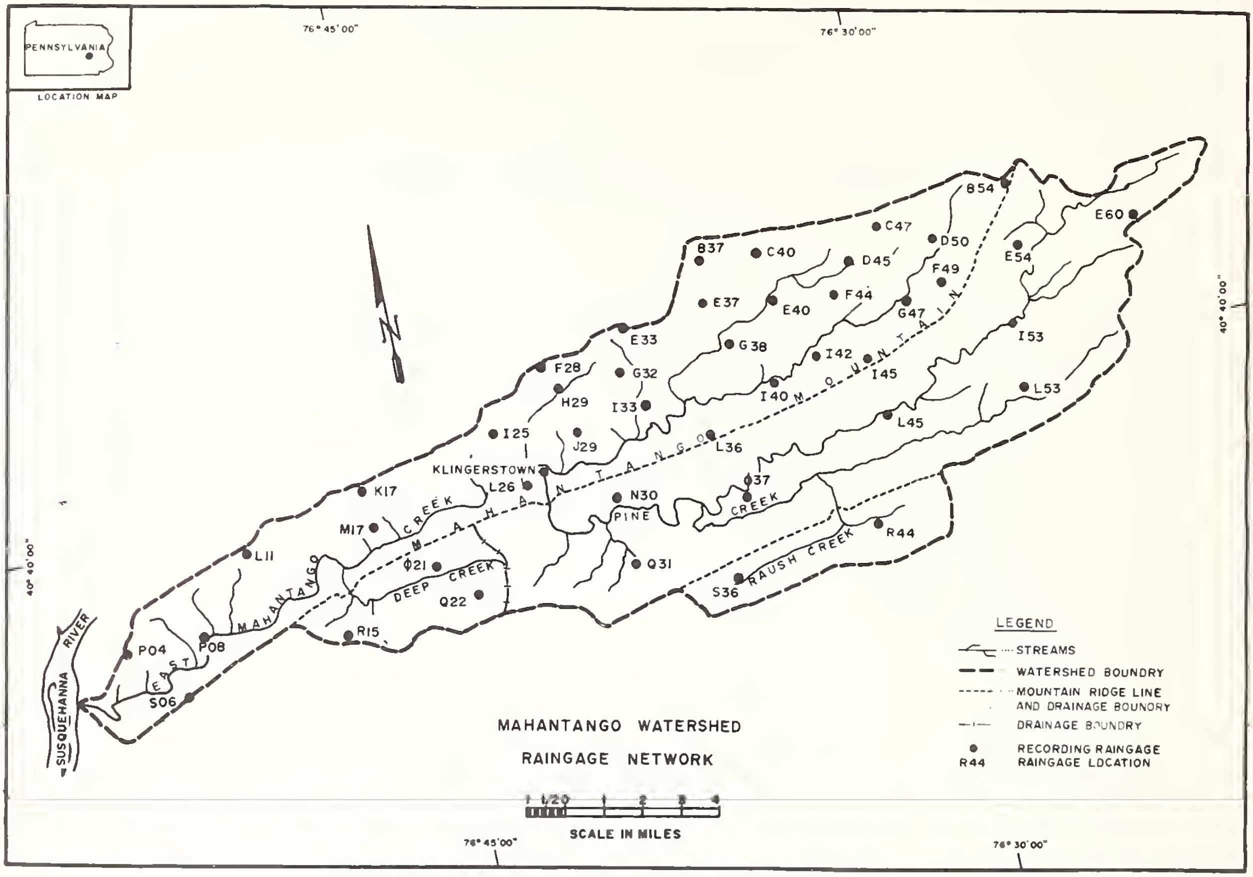


Figure 1.—Rain gage network, Mahantango watershed, Pa.

GENERAL CLIMATIC FEATURES

The climate of the research watershed is typical of that for the eastern Pennsylvania section. The summers are warm; the winters are quite cold, long and oftentimes associated with snow and much cloudy or foggy weather. Temperatures over the watershed do not tend to vary greatly with the mountain ridges, which are normally a few degrees cooler than the valley floors throughout the year. Records from the U.S. Weather Bureau stations in the general vicinity of this watershed indicated that annual precipitation is fairly constant from one section of the watershed area to another. The records from these stations indicate a range from about 41 to 49 inches annually. In contrast, local farmers on the watershed report large differences in precipitation from one valley to another. One fact that might support these reports is a 9-year annual mean of 31 inches recorded at Gratz, which was one of two U.S. Weather Bureau stations within the watershed boundaries. The U.S. Weather Bureau station at Selinsgrove, Pa., 13 miles northwest of Klingerstown, is considered as most representative of the entire watershed area. A long-term mean precipitation of 41 inches was recorded at this station.

RAIN GAGE NETWORK

The Mahantango rain gage network was begun in the latter part of 1966, with 41 gages in operation. Two gages were installed in the latter part of 1968, completing a network of 43 gages. The rain gage location numbers, date of installation, and elevations are given in table 1. Each gage location was chosen to sample the range in elevation and provide uniform areal coverage. The design of the network affords major coverage to the upper half of East Mahantango Creek and Pine Creek Basins, and, at the same time, provides sufficient coverage in the Rausch and Deep Creek areas. The map of Mahantango watershed rain gage network gives a pictoral view of the gage coverage (fig. 1). The rain gages comprising this network are of the Fischer and Porter digital punch tape type.

Table 1.—Rain gage identification, Mahantango watershed

Recording gage no[1]	Installation date	Gage elevation	Recording gage no.[1]	Installation date	Gage elevation
		Feet			*Feet*
J29	10/30/66	890	L26	12/31/66	540
G32	12/31/66	900	M17	1/24/67	660
E33	12/31/66	980	O21	1/24/67	710
F28	12/31/66	970	I25	12/23/66	750
H29	12/31/66	700	L11	1/3/67	740
I33	12/31/66	750	P08	1/16/67	440
B54	[1] 12/29/67	1,670	S06	12/27/67	950
I45	12/31/66	1,430	Q22	1/23/67	750
F49	12/31/66	1,150	Q31	1/20/67	650
D50	12/31/66	1,020	O37	12/27/66	850
C47	12/31/66	1,070	N30	1/23/67	630
C40	12/31/66	920	R44	1/24/67	1,050
E40	12/31/66	730	L45	1/24/67	680
E37	12/31/66	770	L53	12/27/66	820
B37	12/31/66	910	E54	1/24/67	920
L36	12/14/67	1,450	K17	1/24/67	770
I42	12/31/66	860	I53	1/24/67	830
I40	12/31/66	680	R15	12/15/67	690
G38	12/31/66	850	E60	3/31/67	1,740
D45	12/31/66	920	S36	10/18/68	1,180
G47	12/31/66	820	P04	12/18/68	700
F44	12/31/66	980			

[1] Record terminated November 26, 1969.

Recording accuracy for these pages is to the nearest one-tenth of an inch. To provide a more accurate timing of precipitation occurrence, a rain trace indicator is incorporated into the gages during the nonfreezing season of the year. This trace indicator depicts beginning and ending times of rainfall events. Electronic timers set for 5 minute intervals are used on the precipitation gages.

BASIC DATA

Basic data collected from the precipitation gages are of the binary-coded paper tape form. These tapes contain a precipitation depth for each 5-minute interval during the collection period. The paper tapes are removed from gages every month, at which time each tape is hand reviewed for possible errors and labeled as to gage location, recording period, and tape conditions. The information from the reviewed tapes is then transferred to computer-compatible magnetic tape by means of a paper tape translator. Computer programs are used to edit translator tapes into a breakpoint tabulations format by discarding all 5-minute intervals of zero precipitation values. This edited data of date, time, and precipitation depth are stored on magnetic tape as a master data file. Translation and editing of information is done annually.

The data collected from the research watershed for 1967 are in the paper tape form. Translation was not attempted because of numerous instrument failures during the collection period. Annual precipitation totals were obtained for this period. The 1968 and 1969 data are scheduled for translation and editing in mid-1970.

PRECIPITATION CHARACTERISTICS

The mean annual precipitation on the watershed for 1967 was equal to the mean at Selinsgrove. Meanwhile, the totals for 1968 and 1969 were 4 and 2 inches below this mean, respectively. The distribution of annual precipitation during 1967 and 1968 over the watershed tends to show greater amounts along the Sesquehanna River, and decreasing amounts in a direction into the watershed basin and away from the river. On the other hand, the 1969 distribution was a reversal of the 1967 and 1968 distributions, showing lesser amounts along the river. In all cases, the mountain ridges produced larger precipitation amounts than did their adjacent valleys. An isohyetal plot of annual precipitation for 1967 is given in figure 2; the plot for 1968, in figure 3; and the plot for 1969, in figure 4. The long-term average annual snowfall depth for this area is about 41 inches. The snowfall on the watershed for the period of record has been below this average.

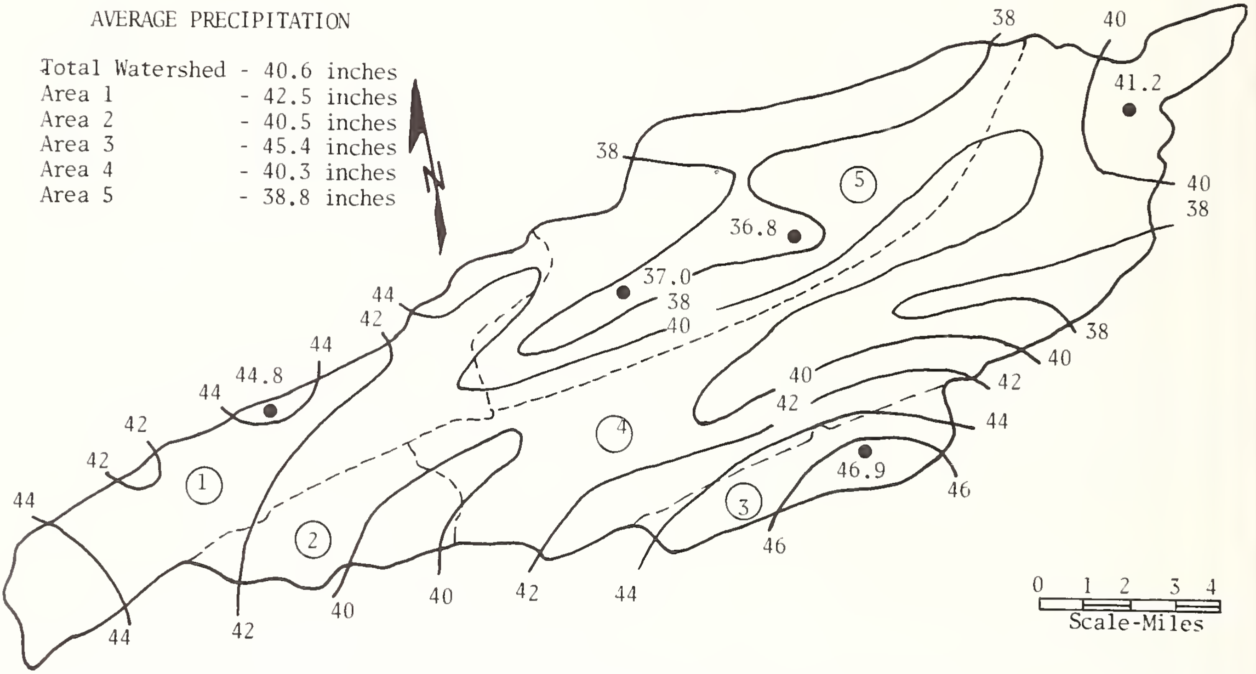
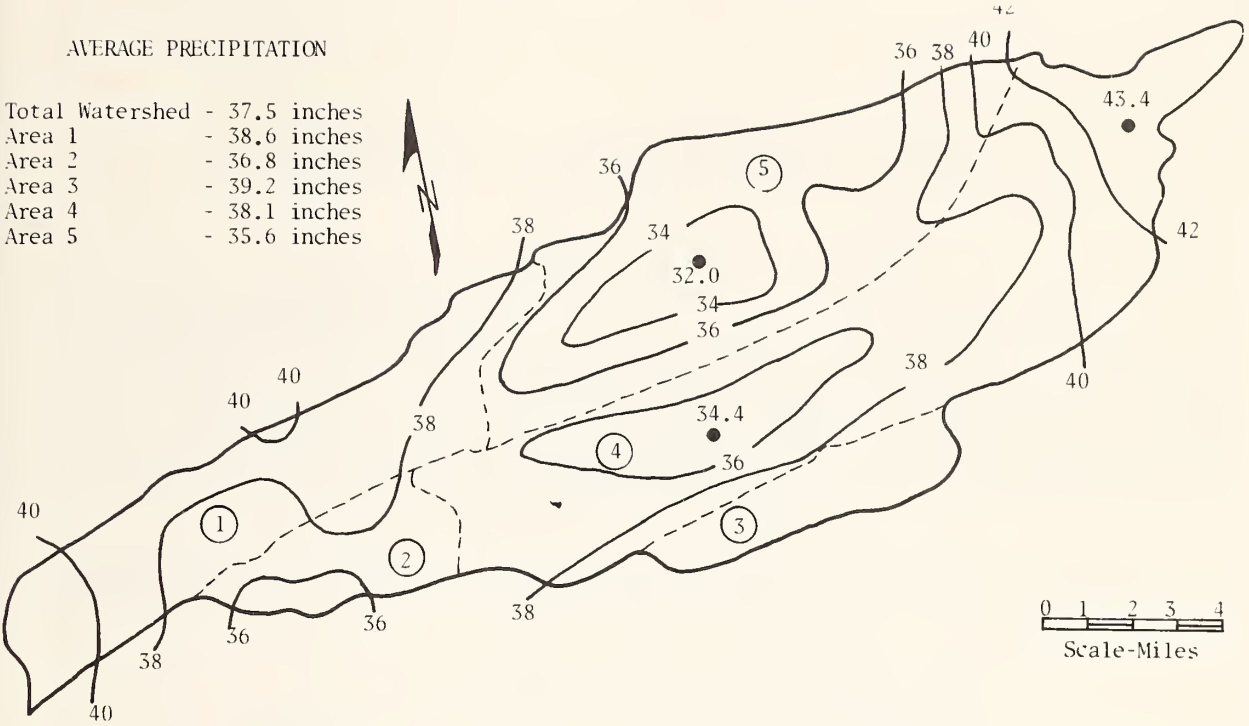
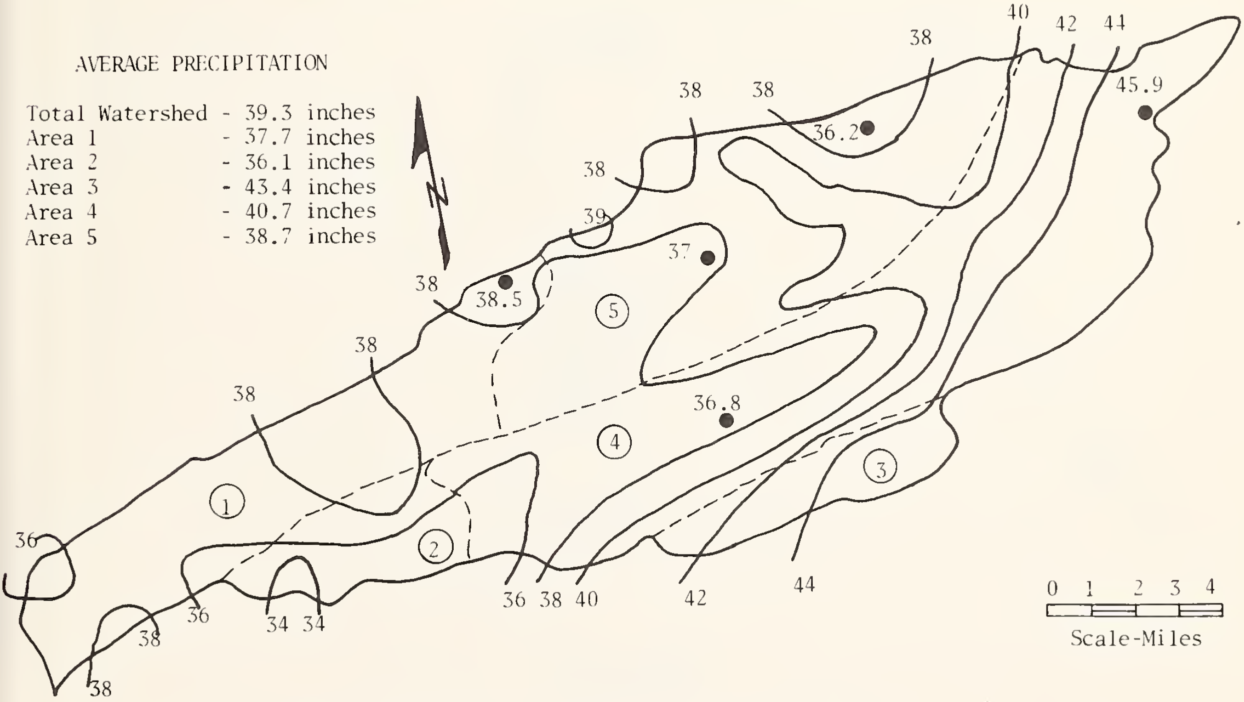


Figure 2.–Manhantango watershed annual rainfall (inches) for 1967.


AVERAGE PRECIPITATION

Total Watershed - 37.5 inches
Area 1 - 38.6 inches
Area 2 - 36.8 inches
Area 3 - 39.2 inches
Area 4 - 38.1 inches
Area 5 - 35.6 inches

Figure 3.—Manhantango watershed annual rainfall (inches) for 1968.


AVERAGE PRECIPITATION

Total Watershed - 39.3 inches
Area 1 - 37.7 inches
Area 2 - 36.1 inches
Area 3 - 43.4 inches
Area 4 - 40.7 inches
Area 5 - 38.7 inches

Figure 4.—Manhantango watershed annual rainfall (inches) for 1969.

CHAPTER 12.--COTTONWOOD, S. DAK.

Clayton L. Hanson[1]

The Cottonwood Range Field Station is approximately 75 miles east of Rapid City (fig. 1) and is a part of the South Dakota Agricultural Experiment Station.

Watershed study areas were established in each of three differentially grazed pastures in 1962. Confining dikes were constructed on four 2-acre contiguous watersheds (fig. 2) on each of the three pastures. The soils are slowly permeable heavy clays derived from the Pierre Formation with slopes averaging 7.8 percent. Each set of watersheds has a northeast aspect. The lightly and heavily grazed watersheds lie about one-quarter mile on either side of the moderate watersheds. Two-foot H-flumes and FW-1 waterstage recorders measure runoff. Four 8-inch recording rain gages measure the precipitation on each set of watersheds.

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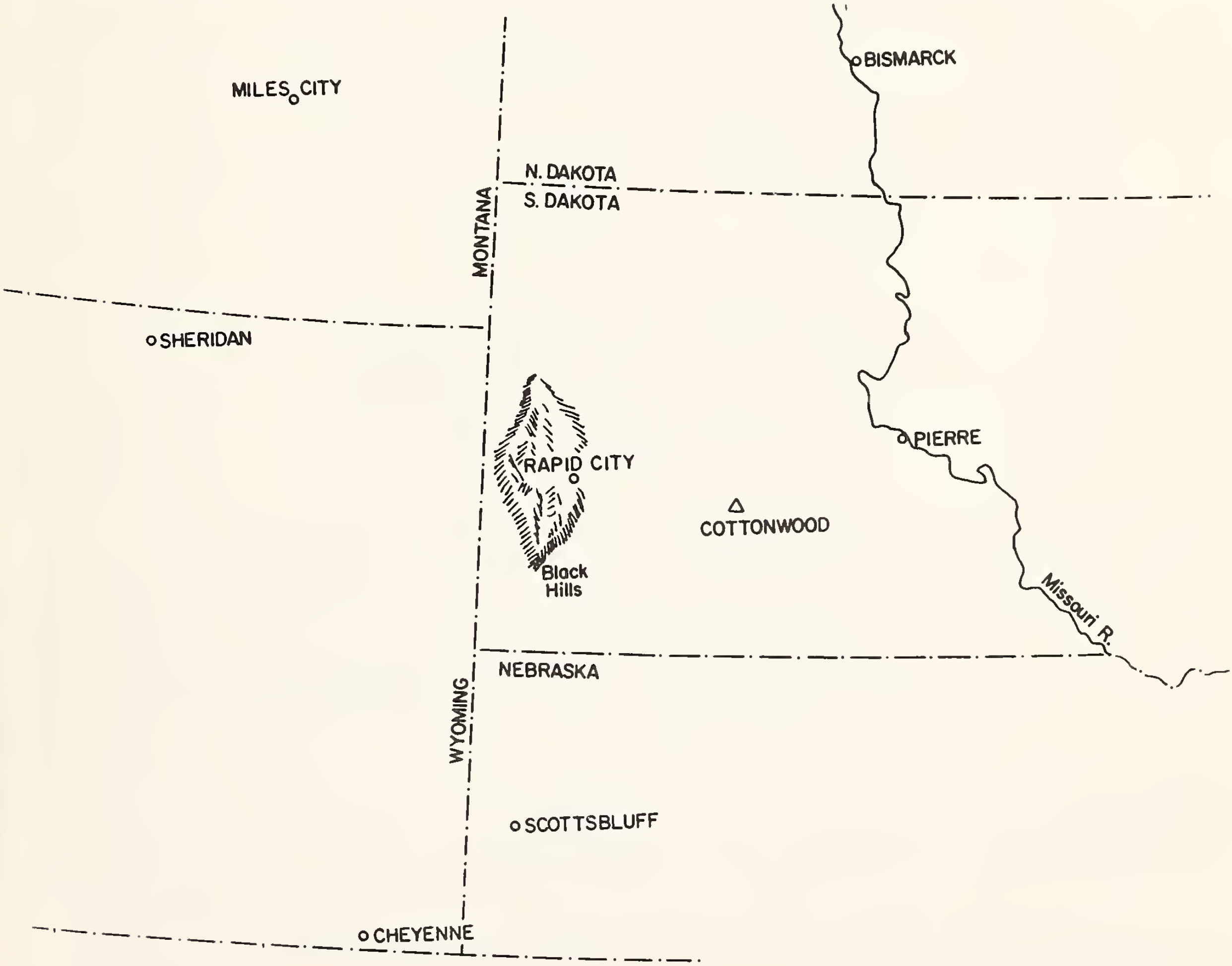

Figure 1.–Location of Cottonwood Range Field Station, S. Dak.

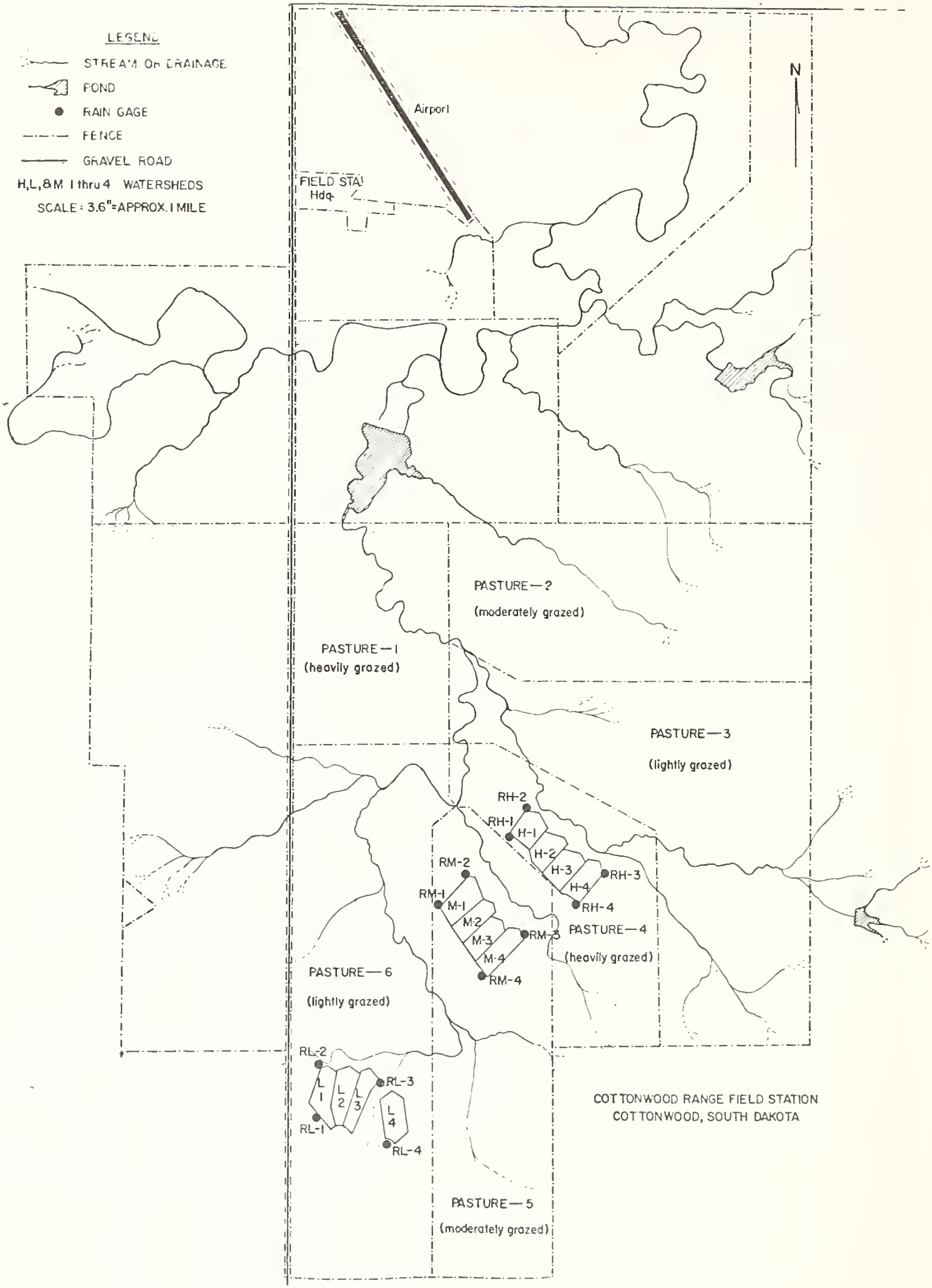

Figure 2.—Rain gage locations and land use for Cottonwood, S. Dak.

The pastures had been grazed heavily, moderately, and lightly since 1942. Fixed stocking rates were used through 1951. Since 1952 "put-and-take" animals have been used to assure forage utilization to over 55 percent for the heavy use, 35 to 55 percent for the moderate use, and less than 35 percent for the light use.

Before the grazing intensity study was begun, this mixed prairie area was dominated largely by midgrasses with an understory of short grasses and sedges. In the last 28 years under three intensities of controlled grazing, the midgrasses have deteriorated on the moderately and heavily grazed watersheds, leaving the short grasses and sedges.

The rain gage network associated with the watersheds is used primarily to determine the relationships between precipitation and runoff as affected by the intensity of grazing (light, moderate, and heavy) on rangeland in the fine-textured soils area of western South Dakota.

Table 1 lists the installation data, type, and approximate elevation of each of the gages. The data have been tabulated for daily, monthly, and annual amounts. All of the data are on charts with the exception of the nonrecording gage at the experiment station headquarters, which is read daily.

Table 1.—Rain gages, Cottonwood, South Dakota
[Latitude 43° 58′, longitude 101° 52′]

Gage no.[1]	Approximate gage elevation
Rain gage network:[2]	*Feet*
RH-1	2,435
RH-2	2,410
RH-3[3]	2,410
RH-4	2,440
RM-1[3]	2,465
RM-2	2,440
RM-3[3]	2,440
RM-4	2,470
RL-1[3]	2,510
RL-2	2,480
RL-3	2,480
RL-4	2,510
Cottonwood Range Field Station[4]	2,414

[1] All gages are weighing-recording type, except as footnoted.
[2] Installed Jan. 1, 1963.
[3] Not in operation from approximately Nov. 1 to Apr. 10 annually.
[4] U.S. Weather Bur. nonrecording gage installed June 1909.

Data from 1910 through 1967 show that the mean annual precipitation at the experiment station headquarters is 15.22 inches and has ranged from 7.13 inches in 1936 to 27.62 inches in 1915.[2] During the growing season, thunderstorms are associated with most of the precipitation, and therefore there is a wide range of amounts and intensities of rain. June is the month of highest precipitation with an average of 2.99 inches. The driest month is December when the average precipitation is 0.35 inch. The greatest monthly precipitation was 9.47 inches in June 1967, and the greatest daily amount was 4.00 inches on May 26, 1915. June is the only month that has an average of 1 day per month with 1 inch or more precipitation. This region can expect a rainfall of 2 inches or more in a 1-hour period about once in 12 years.[3]

Table 2 lists the annual and seasonal (May 14-October 31) precipitation on the watershed from 1963 through 1969. The 7-year mean is 0.18-inch less than the 58-year mean of 15.22 inches recorded at the field station headquarters.[4] The seasonal precipitation (May 14-October 31) is about two-thirds of the annual total. The period from May 14 through October 31 is separate because there was no snowmelt runoff during this period.

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[2] Spuhler, Walter, Lytle, W. F., and Moe, Dennis. Climatography of the United States, Nos. 20-39, U.S. Weather Bur. Climatol. Sum. 14. 1968.

[3] See footnote 2.

[4] See footnote 2.

Table 2.—Annual and seasonal (May 14-October 31) precipitation on the watershed areas, Cottonwood, S. Dak.

Year	Precipitation	
	Annual	Seasonal
	Inches	*Inches*
1963	15.34	12.26
1964	13.46	8.30
1965	15.34	10.92
1966	14.20	9.34
1967	16.66	11.02
1968	14.58	10.80
1969	15.68	12.06
Mean	15.04	10.67

The data from 1963 through 1969 show that there were an average of better than two 1-inch or greater precipitation events per year (table 3). There were six rainfall events greater than 2 inches, and, in 1963 two 3-inch rainfalls. The first 3-inch rain in 1963 was on May 30. The maximum 10-minute intensities during the May 30 storm varied from 7.20 inches per hour at gages RL-1 through RL-4 to 4.80 inches per hour at RH-1 through RH-4. The second 3-inch rainfall was on June 15. The maximum 10-minute intensity in this storm was about 1.4 inches per hour.

Hail can be expected about two to three times per year with the most frequent occurrence in June.[5]

Snow accounts for approximately 13 percent of the annual precipitation with an average annual snowfall of 25.6 inches. March has an average snowfall of 5.8 inches, which is the highest for any one month.

It has been estimated that one-half of the time the annual maximum flood occurs during the spring breakup, and the other half of the time the annual maximum flood is due to rain.[6]

Table 3.—Summary of precipitation events from recording rain gages, Cottonwood, S. Dak.

Year	Amounts in inches				
	0.50-0.99	1.00-1.49	1.50-1.99	2.00-2.49	Over 2.49
	Average number of events[1]				
1963	6	—	—	—	2
1964	6	2	—	—	—
1965	7	—	1	—	—
1966	2	—	1	2	—
1967	5	—	2	1	—
1968	5	2	—	—	—
1969	6	—	1	1	—

[1] Mean of 12 recording gages.

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(1) Rauzi, Frank, and Hanson, Clayton L.
1966. Water intake and turnoff as affected by intensity of grazing. Jour. Range Mangt. 19: 351-356.

(2) Sharp, A. L., and others.
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[5] Stout, Glenn E., and Changnon, Stanley A., Jr. Climatography of hail in the Central United States. Crop Hail Insurance Actuarial Assoc., CHIAA Res. Rpt. 38, 49 pp. Chicago. 1968.

[6] McCabe, John A., and Crosby, Orlo A. Floods in North and South Dakota, frequency and magnitude. U.S. Geol. Surv., Open File Rpt., Bismarck, N. Dk. 132 pp. 1959.

CHAPTER 13.--NEWELL, S. DAK.

Clayton L. Hanson[1]

A network of 17 recording rain gages and 32 storage rain gages are distributed over a 1,000-square-mile area of western South Dakota (fig. 1).

The rain gage network is used primarily to measure precipitation for developing methods for estimating water and sediment yields from rangeland watersheds in the D-4, D-10, and D-11 conservation problem areas of the Northern Great Plains as represented by sites on moderately coarse- and fine-textured soils in western South Dakota. To accomplish these objectives, 32 watersheds on moderately coarse-textured soils and 26 on fine-textured soils were selected and instrumented in 1962. The recording gages are serviced weekly, and the storage gages are read biweekly or monthly depending on the amount of preciptation. Runoff from the watersheds is measured with continuous water stage recorders, and the water stages of the other reservoirs are observed and measured periodically throughout the year. Periodic volume surveys of the reservoirs are used to determine the sediment yield from the watersheds.

Tables 1 and 2 list the length of record, type, and approximate elevation of each of the gages.

The data have been tabulated for daily, monthly, and annual amounts. All of the data are on charts with the exception of the storage gages and the nonrecording gage.

Data for 1908 through 1965 show that the mean annual precipitation at the Newell Experiment Station is 15.47 inches and has ranged from 6.64 inches in 1911 to 28.04 inches in 1946. During the growing season, thunderstorms are associated with most of the precipitation, and, therefore, there is a wide range of amounts and intensities of rain. June is the month of highest precipitation with an average of 3.07 inches. Driest months are December through February, which receive about 0.4 inch of precipitation each. The greatest monthly amount of precipitation was 9.35 inches in May 1946, and the greatest daily amount was 4.00 inches on May 10, 1920. June is the only month that has an average of 1 day per month with 1 inch or more of precipitation. This region can expect a rainfall of 2 inches or more in a 1-hour period about once in 20 years.[2]

The mean annual precipitation for the seven recording gages that have been in operation from 1958 through 1968 is 13.6 inches. The 7-year mean for these gages ranged from 15.27 inches at gage W-5A to 12.23 inches at gage W-2A. The maximum annual precipitation ranged from 22.60 inches in 1962 at gage W-12A to 8.21 inches in 1961 recorded by gages W-13B and C. Data from these gages also shows that 1 inch of precipitation or more in a 24-hour period can be expected about twice per year (table 3). Three inches or more rain in a 24-hour period occurred only three times, twice at gage W-14A and once at W-15A. The greatest 24-hour rainfall was 3.54 inches recorded by gage W-15A in July 1958. The monthly variation of precipitation due to thunderstorms is illustrated by data for June 1966, when about 1 inch of precipitation fell at gage W-14A and 5.75 inches fell at gage W-5A.

Hail can be expected two to three times per year on the northwestern section of the network and a little over three times per year on the southeastern section of the network.[3] Hail occurs most frequently during June. There has been one destructive hail storm at the Newell Experiment Station during the past 10 years.

Snow accounts for approximately 13 percent of the annual precipitation with an average annual snowfall of 21.1 inches. March has an average snowfall of 4.7 inches, which is the most for any 1 month.[4]

It has been estimated that one-half of the time the annual maximum flood occurs during the spring breakup and the other half of the time the annual maximum flood is due to rain.[5]

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[1] Agricultural engineer (USDA), Institute of Atmospheric Science, South Dakota School of Mines and Technology, Rapid City, S. Dak. 57701.

[2] Spuhler, Walter, Lytle, W. F., and Moe, Dennis. Climatography of the United States, Nos. 20-39, U.S. Weather Bur. Climatol. Sum. 10. 1968.

[3] Stout, Glenn E., and Changnon, Stanley A., Jr. Climatography of hail in the Central United States. Crop Hail Insurance Actuarial Assoc., CHIAA Res. Rpt. 38, 49 pp. Chicago. 1968.

[4] See footnote 2.

[5] McCabe, John A., and Crosby, Orlo A. Floods in North and South Dakota, frequency and magnitude. U.S. Geol. Survey Open-File Rpt., 132 pp. Bismarck, N. Dak. 1959.

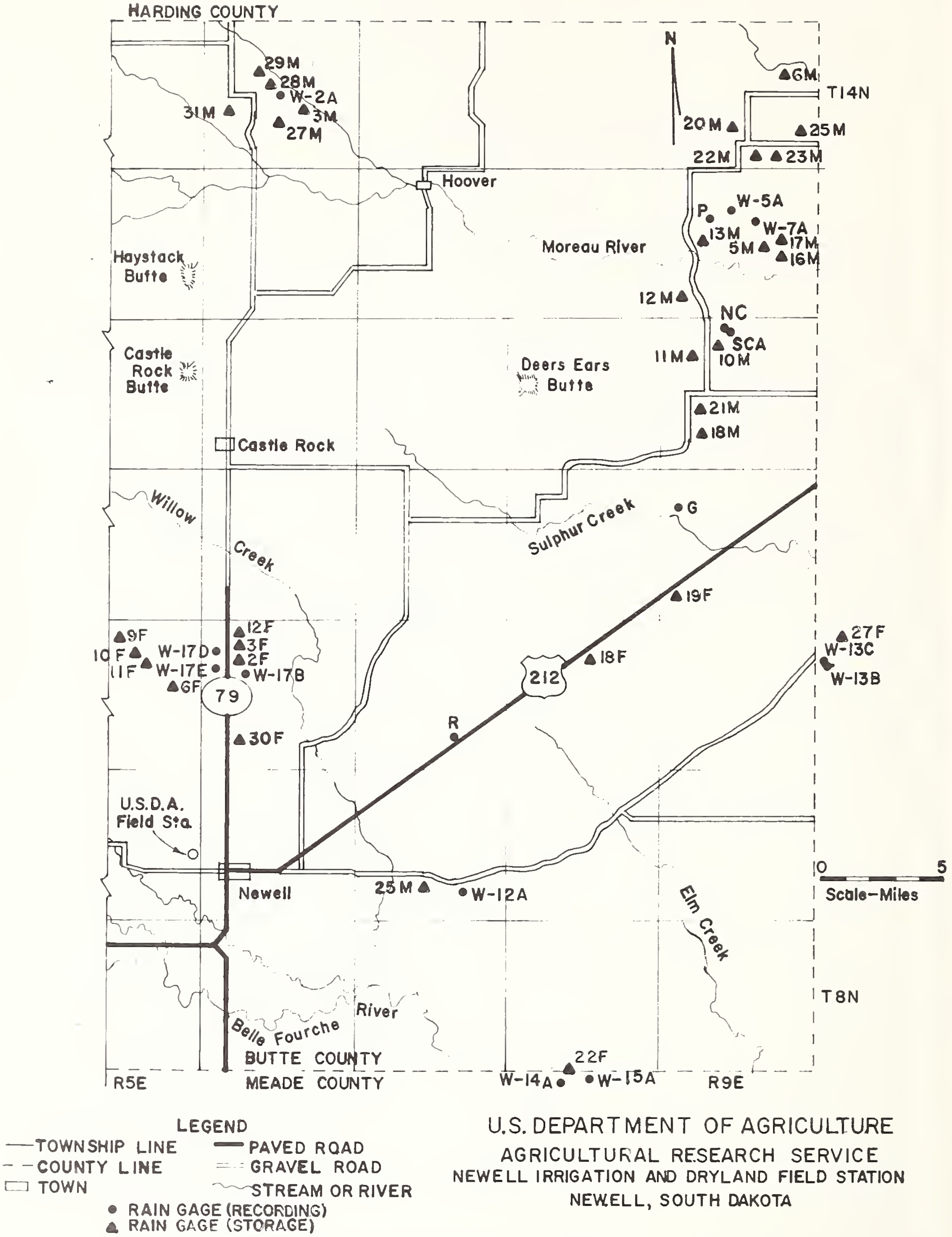

Figure 1.—Rain gage network, Newell, S. Dak.

Table 1.—Rain gages, Newell, S. Dak.
[Latitude 44° 44′, longitude 103° 27′]

Gage no.[1]	Installation date	Approximate gage elevation above mean sea level
		Feet
W-2A	May 2, 1958	2,900
W-5A	Jan. 26, 1958	2,810
W-7A	....do.....	2,810
W-12A	Feb. 17, 1958	2,880
W-13B	Feb. 11, 1958	2,750
W-13C[2]	....do.....	2,820
W-14A	Apr. 3, 1958	2,830
W-15A	Mar. 18, 1958	2,830
R (Richards)	Apr. 16, 1962	2,950
G (Gruwell)	Aug. 24, 1962	2,800
SCA	June 20, 1963	2,840
NC	May 6, 1966	2,840
P (Price)	Aug. 21, 1962	2,800
W-17B	Apr. 6, 1961	3,010
W-17D[2]	Apr. 17, 1961	3,010
W-17E	May 19, 1961	3,010
Newell Field Station[3]	Jan. 1908	2,870
Newell Field Station	Oct. 22, 1962	2,870

[1] All rain gages are of recording type except as footnoted.
[2] Not in operation from approximately Nov. 1 to April 10 annually.
[3] U.S. Weather Bureau nonrecording gage.

Table 2.—Storage rain gages, Newell, S. Dak.
[Latitude 44° 44′, longitude 103° 27′]

Gage no.[1]	Approximate gage elevation above mean sea level
	Feet
3M	2,900
6M	2,750
10M	2,800
11M	2,850
12M	2,850
13M	2,750
15M	2,800
16M	2,800
17M	2,800
18M	2,800
20M	2,750
21M	2,800
22M	2,800
23M	2,800
25M	2,850
27M	2,900
28M	2,900
29M	2,900
31M	2,850
2F	2,920
3F	2,950
6F	3,110
9F	3,120
10F	3,100
11F	3,100
12F	2,950
18F	2,900
19F	2,900
22F	2,840
25F	2,900
27F	2,790
30F	3,010

[1] All are storage gages installed June 1962.

Table 3.—Summary of 24-hour precipitation from seven recording rain gages, Newell, S. Dak.

Year	Amounts in inches				
	0.50-0.99	1.00-1.49	1.50-1.99	2.00-2.49	Over 2.49
	Average number of events[1]				
1958	4.1	0.7	0.2	—	0.1
1959	2.6	.1	—	0.1	—
1960	2.4	.9	.7	—	—
1961	3.4	.7	—	—	.3
1962	8.9	1.9	1.0	.1	—
1963	5.0	1.4	.3	—	.4
1964	3.0	1.0	1.4	.1	—
1965	5.3	3.3	—	—	—
1966	3.3	.9	.9	—	.4
1967	4.0	2.6	.4	.1	.3
1968	6.0	.9	.1	—	—
1969	4.4	.3	.6	.1	—

[1] Mean of seven recording gages.

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(2) Kuhlman, Armine R.
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(3) ________ and Hanson, Clayton L.
1966. Panspots range sites produce more runoff than sandy range sites. Jour. Soil and Water Conserv. 21: 175-176.

(4) Neuberger, J. W., Sharp, A. L., and Kuhlman, A. R.
1964. Precipitation-runoff relationships on western South Dakota watersheds. S. Dak. Farm & Home Res. 15(1):6-9.

CHAPTER 14.--RIESEL, TEX.

Walter G. Knisel, Jr., and Ralph W. Baird[1]

Precipitation data have been collected in the Blacklands Experimental Watershed near Riesel, Tex., since 1937. Rain gage networks of various densities have been maintained on the 9.6-square-mile area for 32 years. The network on the Federally owned land has been more dense than that on the surrounding Brushy Creek drainage area. Also, observations at three locations in the Federally owned area have been continuous, whereas the network on Brushy Creek was discontinued for a period beginning in 1943. Recording rain gage locations are shown in figure 1 and the gage designations refer to the numbers given in table 1. This table also lists the period of record and elevation for each location.

Relief of the Blacklands Experimental Watershed is gently rolling to nearly level. Elevations range from 464 to 592 feet above mean sea level. Approximately 86 percent of the area has a 0- to 3-percent slope, 10 percent has a 3- to 6-percent slope, and only 4 percent has slopes greater than 6 percent. The hillsides slope gently into broad drainageways and flood plains.

The primary objective of the rain gage network in the Blacklands Experimental Watershed is to furnish basic data for runoff, ground water, and sedimentation studies in the watershed. Other objectives are to determine (1) rainfall variability over small areas, (2) rainfall depth-area relationships, (3) storm sequence rainfall, and (4) rainfall depth-frequency relationships.

Precipitation data reduction has been kept current with the same method for the entire period of record, i.e., breakpoint tabulation for all gages for all events greater than 0.10 inch in amount. Only total precipitation is tabulated for storm events less than 0.10 inch in amount and for freezing rain, sleet, snow, or hail. The reduced data obtained since 1960 have been placed on punchcards. From 1937 through 1960 the reduced data were typed in tabular form.

Average annual precipitation at the Blacklands Experimental Watershed was 33.63 inches for 1937-68. Most of the precipitation was associated with Canadian continental and Pacific maritime frontal movements. The largest monthly amounts normally occur in April, May, and June. A summary of maximum, minimum, and average monthly and annual precipitation amounts is shown in table 2. Convective thunderstorms occur during the summer months but generally do not produce large amounts of rainfall. Tropical cyclones, or hurricanes, have moved inland from the Gulf of Mexico twice (September 1942 and September 1961) during the 32-year period of record.

Distribution of rainfall amount by size of storm at rain gage 69 (central net station) is shown in figure 2. A storm is defined as any period of rainfall with less than a 6-hour lapse without rainfall. During the 32-year record, an average of 70 storms occurred on 75 days per year. Only two storms during the 32 years have produced more than 7 inches of rainfall and only eight have produced more than 5 inches. However, short storm periods have accounted for large amounts. Maximum observed 2-day rainfall was 9.35 inches; 4-day, was 13.22 inches; 7-day, was 13.90 inches; and 15-day, was 15.47 inches. Knisel[2] related 1-day rainfall to 2-, 4-, 7-, and 15-day rainfall for 47 locations in Texas. The relation by time interval is shown in figure 3, and the relatively small increase from 4-day to 7-day rainfall is obvious.

The low relief of the Blacklands Experimental Watershed is not sufficient to cause orographic influence on precipitation. The maximum difference between rain gage elevation is only 91 feet.

Freezing rain, sleet, or snow are not hydrologically significant. Snow occurred on the average of once in 2 years during the months of December through March, mainly in January and February. Each storm averaged 0.14 inch of water equivalent, and the maximum depth of snow accumulated on the ground was 2.2 inches. Freezing rain

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[1] Research hydraulic engineers, Blacklands Experimental Watershed, P.O. Box 1147, Riesel, Tex. 76682.

[2] Knisel, W. G., Jr. Rainfall frequency analysis for 1- to 15-day durations in the Blacklands of Texas, U.S. Dept. Agr., Agr. Res. Serv. ARS 41-106, 13 pp. 1965.

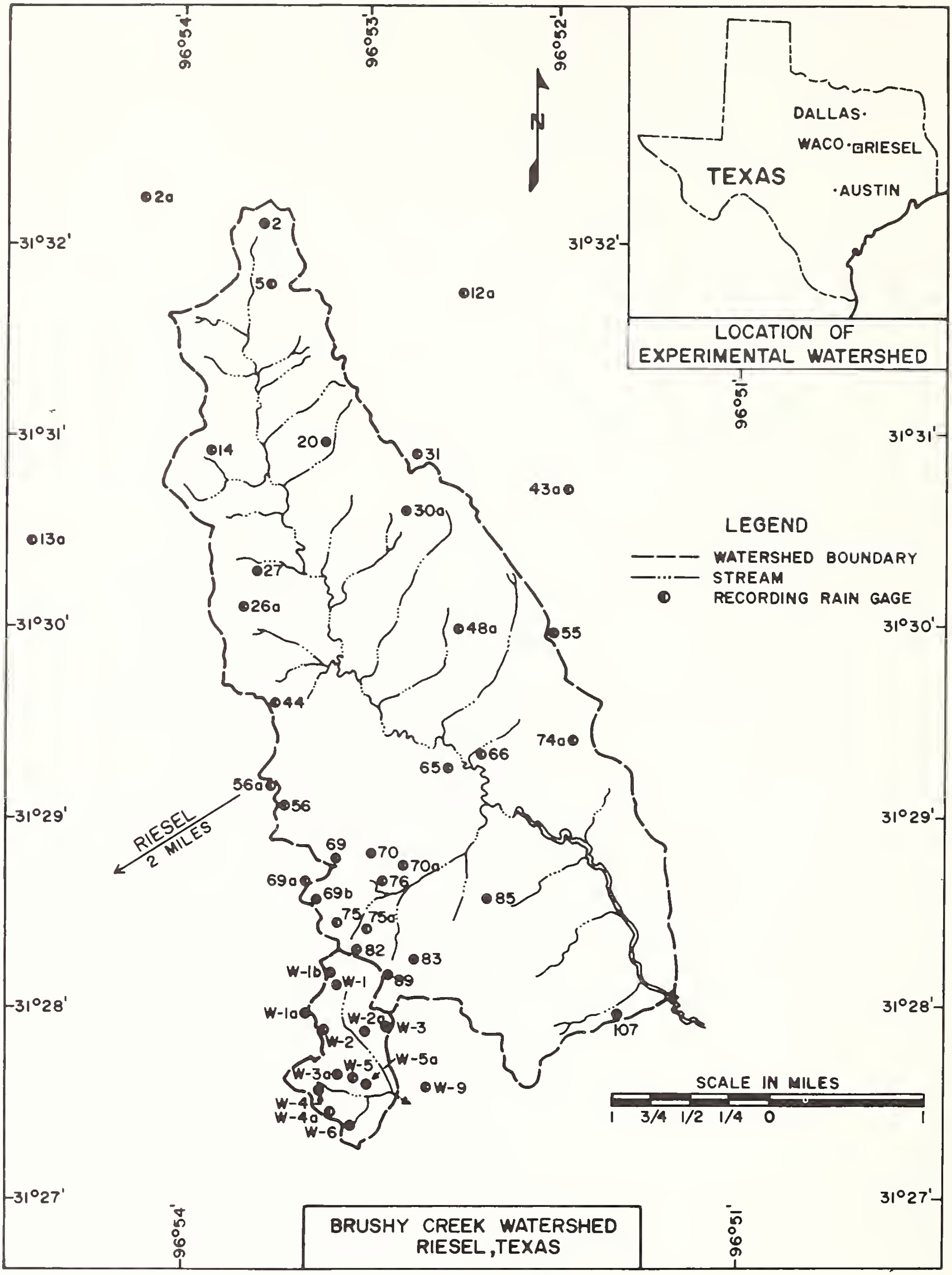

Figure 1.–Brushy Creek Watershed, Riesel, Tex.

Table 1.–Rain gage network description for Blacklands Experimental Watershed, Riesel, Tex.

Rain gage[1] No.	Period of record		Elevation above mean sea level
	From	To	
	Date	*Date*	*Feet*
2	4-22-38	7-07-43	580
2a	4-28-60	Present	550
5	9-14-36	7-20-43	585
5	2-09-49	Present	
12a	4-28-60	Present	543
13a	4-28-60	Present	540
14	8-27-36	7-20-43	576
14	3-01-49	Present	
20	2-28-44	Present	548
26a	7-01-57	Present	540
27	8-27-36	7-20-43	536
30a	7-01-57	Present	554
31	9-25-37	6-30-42	574
43a	4-28-60	Present	556
44	8-14-36	7-20-43	563
48a	7-01-57	Present	542
55	9-18-36	7-20-43	547
56	2-01-39	7-21-43	544
56a	6-30-57	Present	557
65a	7-01-57	Present	532
66	9-18-36	7-20-43	504
69	9-17-36	Present	572
69a	3-14-38	7-25-43	547
69b	6-30-57	Present	564
70	3-14-38	7-13-43	548
70	4-29-47	Present	
70a	3-24-38	7-13-43	523
70a	1-01-69	Present	
74a	4-28-60	Present	533
75	4-12-38	7-25-43	554
75a	4-29-38	Present	555
76	3-24-38	7-25-43	540
76	10-13-48	5-09-49	
82	3-14-38	7-25-43	565
83	4-16-38	7-25-43	553
84a	4-28-38	7-25-43	524
84a	11-20-46	Present	
85	2-18-37	7-20-43	534
89	4-12-38	7-25-43	563
89	4-29-47	Present	
94	3-26-37	7-20-43	494
107	8-15-36	7-21-43	524
W-1	8-27-36	7-25-43	562
W-1a	4-22-38	12-31-40	564
W-1b	10-01-69	Present	567
W-2	3-24-37	7-25-43	561
W-2	2-26-60	Present	
W-2a	4-29-37	Present	552
W-3	4-12-38	7-25-43	564
W-3	5-31-68	Present	
W-3a	12-19-38	7-25-43	565
W-4	9-18-36	Present	552
W-4a	4-12-38	7-25-43	556
W-5	3-25-37	7-25-43	540
W-5a	10-01-60	Present	540
W-6	3-24-38	Present	560
W-7	4-12-38	7-25-43	541
W-9	4-03-37	7-21-43	517
W-9	1-01-60	5-31-68	

[1] All gages are weighing-recording type with 6-hour time scale.

Table 2.—Maximum, minimum, and average monthly and annual precipitation amounts at the Blacklands Experimental Watershed, 1938-68

Month	Maximum	Minimum	Average
	Inches	*Inches*	*Inches*
Jan.	5.14	0.30	2.37
Feb.	5.75	.35	2.59
Mar.	7.48	.25	2.57
Apr.	15.65	.52	3.94
May	12.56	.66	4.36
June	8.84	.28	3.59
July	6.11	.01	1.58
Aug.	8.95	0	2.02
Sept.	8.29	0	2.61
Oct.	8.48	0	2.45
Nov.	10.25	.10	3.00
Dec.	7.03	.17	2.55
Yearly totals	58.43	18.22	33.63

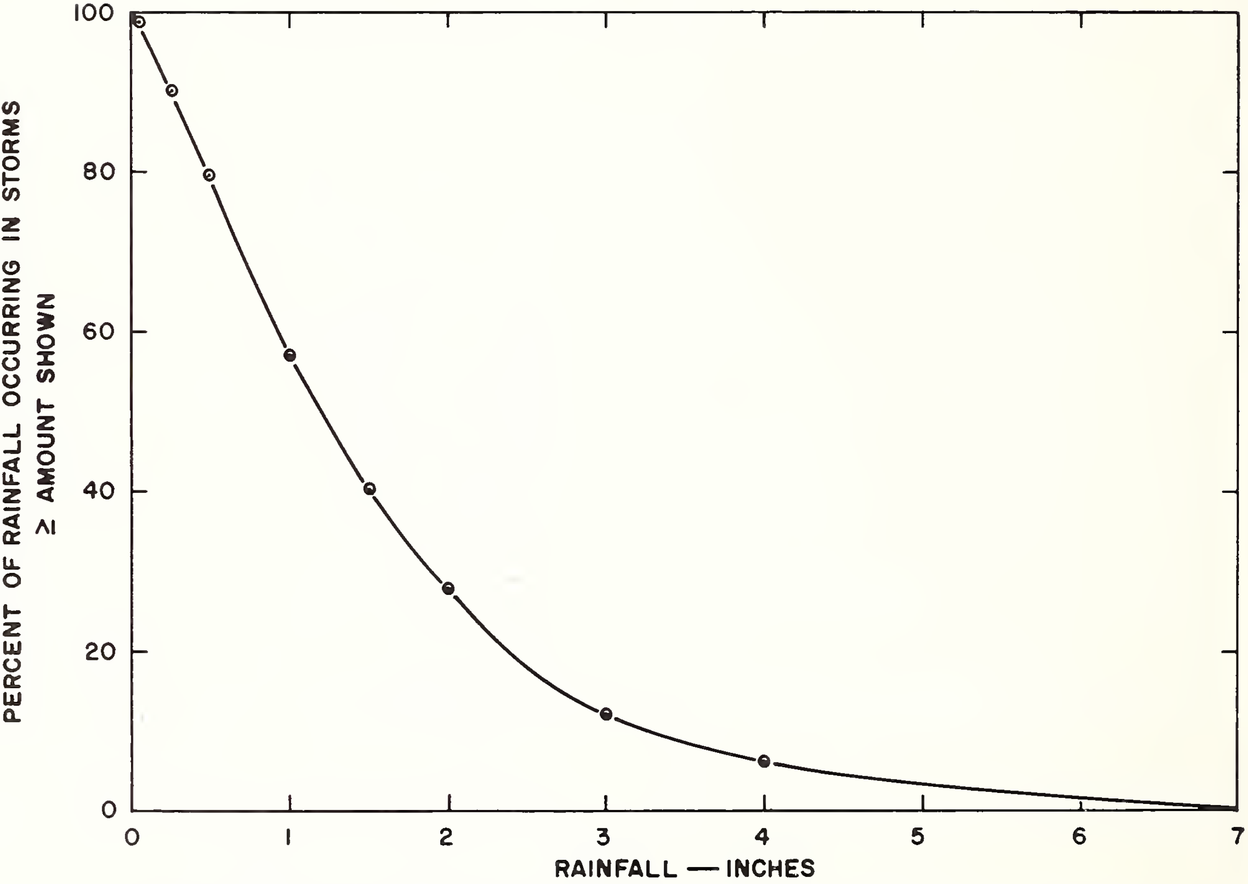

Figure 2.—Distribution of rainfall amount by size of storm at rain gage 69, Blacklands Experimental Watershed, Riesel, Tex., 1937-68.

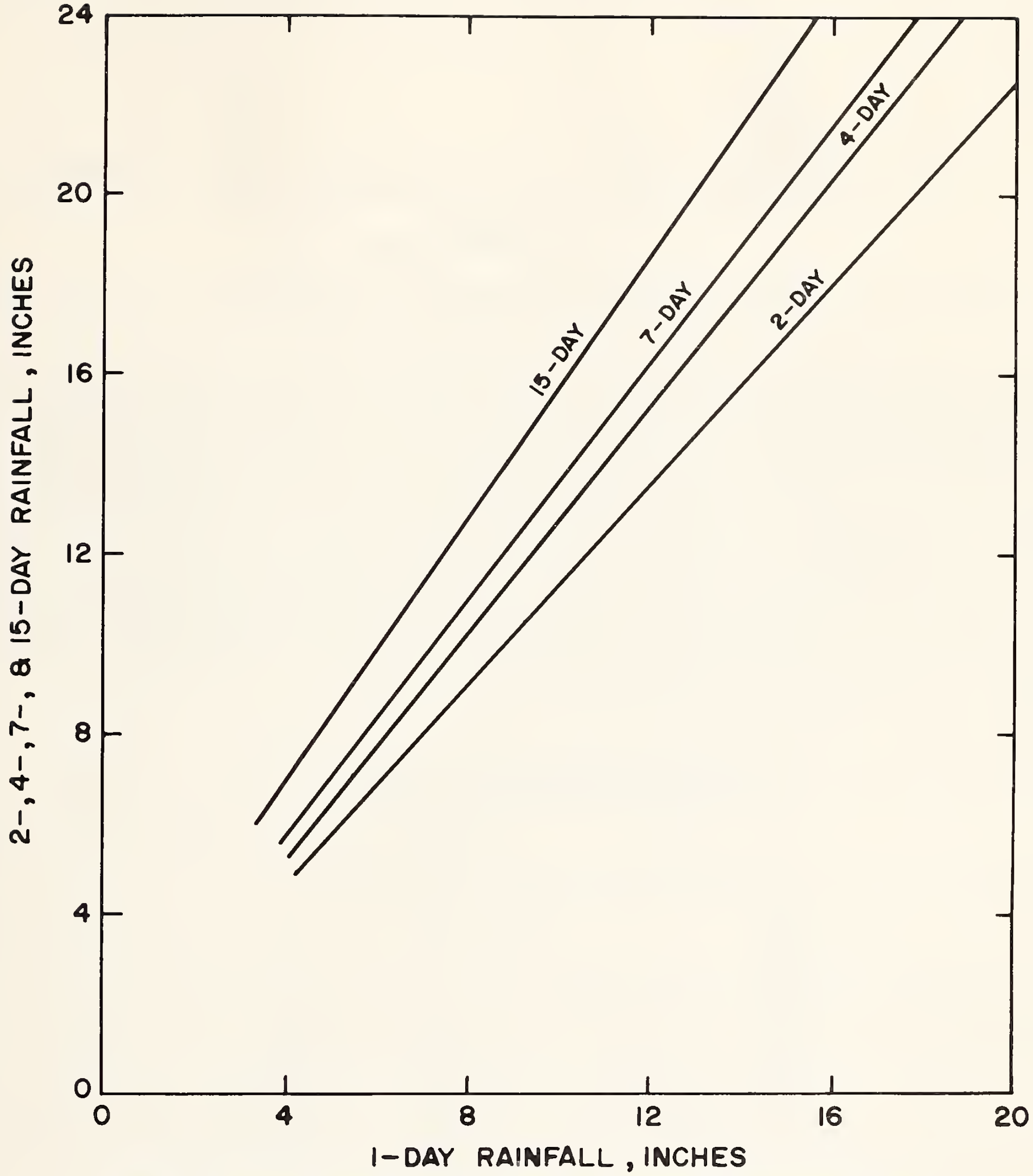

Figure 3.—Relationship between 1-, 2-, 4-, 7-, and 15-day rainfall for the Blacklands of Texas.

and sleet occurred an average of once per year over a 2-day period and produced approximately 0.30 inch of water. Normally, the freezing rain and sleet occur in January and February but have been observed from November through March.

Maximum ratios of areal to point rainfall for storms with expected recurrence of 1 year or more are greater than 0.97 for areas up to 9.6 square miles. For areas less than 1.5 square miles, the maximum ratio is 1.0, and for 2.5 square miles, the maximum ratio is 0.99. Such spatially uniform storms were produced by frontal systems; variability of rainfall from convective thunderstorms is much greater.

Estimations of rainfall over a drainage basin based on records of a single gage located outside the basin can be highly inaccurate. Variability between Thiessen-weighted storm rainfall on a 1.73-square-mile area and rainfall at a single gage increased with an increase in distance to the rain gage from the center of the watershed. The relation between standard deviation and distance from the watershed center is shown in figure 4.

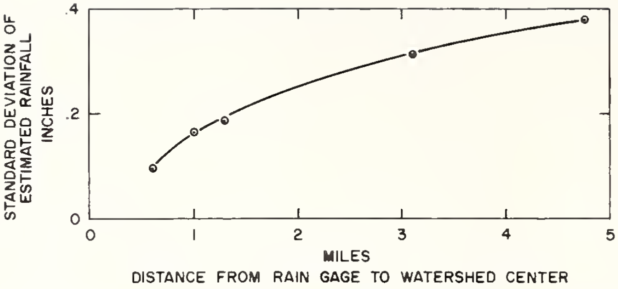

Figure 4.—Relation between standard deviation of watershed and point rainfall and distance of point from center of watershed.

An excessive storm has been defined as one in which the amount of rainfall during any 5-minute period was equal to or greater than 0.25 inch, or one in which the amount for any period in excess of 5 minutes was equal to 0.25 inch plus 0.01 inch for each minute in excess of 5 minutes.[3] Out of a total of 2,239 storms that have occurred at the central meteorological station, only 970 have had 0.25 inch or more rainfall. Only 35 percent of the 970 storms, or a total of 345, were excessive storms as defined. Approximately one-half of the excessive storms did not produce runoff from agricultural areas. Table 3 shows the number of excessive storms per 30 years at Riesel as compared with values predicted by Yarnell. The number of storms per 30 years from the Blacklands Experimental Watershed record is approximately the same as published values for January, February, July, September, and December. Many more storms have been experienced than would be predicted for the remaining 7 months, particularly March through June. The 12-month total observed is 1.65 times greater than that predicted.

Table 3.—Number of excessive storms per 30 years at the Blacklands Experimental Watershed, Riesel, Tex.

Month	Storms predicted	Storms experienced
Jan.	5	6
Feb.	7	7
Mar.	6	23
Apr.	25	46
May	30	62
June	19	51
July	19	17
Aug.	18	26
Sept.	25	26
Oct.	13	22
Nov.	10	19
Dec.	5	6
Totals	182	301

SUMMARY

Most of the precipitation is associated with frontal movement. However, considerable precipitation resulted from two hurricanes which occurred in September 1942 and September 1961. Normally, the largest monthly rainfalls occur in April, May, and June. Orographic influence is not a factor in rainfall production. Although maximum ratios of areal to point rainfall are greater than 0.97 for areas up to 9.6 square miles, average watershed rainfall estimated from a gage located more than 1 mile from the center of the area may be considerably in error. The number of excessive storms experienced was greater than predicted.

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[3] Yarnell, D. L. Rainfall Intensity-Frequency Data. U.S. Dept. Agr. Misc. Pub. 204, 68 pp. 1935.

CHAPTER 15.--SONORA (SUTTON COUNTY), TEX.

Walter G. Knisel, Jr.[1]

Precipitation data have been collected in the Lowrey Draw Watershed near Sonora (Sutton County), Tex., since June 1961. Locations of the 14 weighing-recording rain gages covering the 48-square-mile drainage basin are shown in figure 1. The period of record, time scale, and elevation of each gage are shown in table 1.

Lowrey Draw Watershed lies within the Edwards Plateau physiographic area. The plateau proper is a smooth upland surface with little relief and is dissected by relatively deep, narrow valleys arranged in a dendritic pattern. Approximately 40 percent of the area is upland and 60 percent has moderate to steep slopes on the valley sides. Elevation of the watershed ranges from 2,125 to 2,400 feet above mean sea level.

The primary objective of the rain gage network in the Lowrey Draw Watershed is to furnish basic data for runoff, ground water, and sedimentation studies in the basin. Other objectives are to determine (1) rainfall variability over small areas, (2) rainfall depth-area relationships, and (3) storm sequence rainfall.

Breakpoint tabulations have been made for all gages for rainfall events greater than 0.10 inch in amount. Only total rain gage catch is tabulated for events with less than 0.10 inch and for freezing rain, sleet, snow, or hail. The tabulated data are on punchcards at the Blacklands Experimental Watershed near Riesel, Tex.

Average annual precipitation at Sonora was 22.19 inches for 1962-68 inclusive. Precipitation for the months of April, May, and September resulted largely from Canadian continental and Pacific maritime frontal movements. Convective thunderstorms characterized by high intensity and short duration accounted for significant rainfall amounts in June, July, and August. Little rainfall occurred during the winter (November through March). Average monthly precipitation for 1962-68 is shown in table 2. Although the difference in elevation is 275 feet (220 feet for rain gages), there is no orographic influence on rainfall.

Rainfall distribution by size of storm is shown in figure 2. Only 55 percent of the rainfall occurred in storms greater than 1.0 inch. An average of 51 storms occurred each year. Four of these on the average extended over a 2-day period; thus, there was an average of 55 rainy days per year.

Freezing rain, sleet, and snow occurred on the average of twice a year from November through February. One occurrence was observed in March. Rain, freezing rain, sleet, and snow generally extended into 2 calendar days, and the storms averaged 0.20 inch of water in January and February, 0.40 inch in December, and 0.80 inch in November. Sleet and snow alone have little hydrologic significance. Accumulations of snow up to 3 inches have been observed. From March to November, rain with hail occurred an average of three times per year. Hail accumulations on the ground have been noticeable but have not been significant in runoff production.

Rainfall from convective thunderstorms is highly variable. Flood-producing storms have occurred in small areas of Lowrey Draw with rainfall recorded at only three or four of the 14 rain gages. These storms did not produce major floods for the area as a whole but were quite significant hydrologically for the small area covered. The major flood-producing storms are associated with frontal movement. These are general storms with relatively high ratios of areal rainfall to point rainfall. The relationship between maximum ratios of areal to point rainfall and size of area is shown in figure 3. Storms with 1 inch or more rainfall at any one rain gage were selected for the relation.

The largest observed storm sequence was from September 19 to 24, 1964. Six separate storms occurred, and rainfall ranged from 6.86 to 12.12 inches. The ratio of areal to point rainfall was considerably less for the storm period than the maximum for all individual storms of record as shown in figure 3.

Annual maximum 60-minute rainfall amounts were determined for all rain gages. Frequency analysis of annual maximums from short-term station-year records can be made if two criteria are met: (1) the network is in a meteorologically homogeneous area, and (2) the maximum amounts at the different stations do not occur in the same storm.[2] The Lowrey Draw network meets the first criterion because the long-term mean-annual rainfall is

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[1] Research hydraulic engineer, Blacklands Experimental Watershed, P.O. Box 1147, Riesel, Tex. 76682.

[2] Gilman, C. S. Rainfall. *In* Handbook of Applied Hydrology, pp. 9-28, McGraw-Hill Co. 1964.

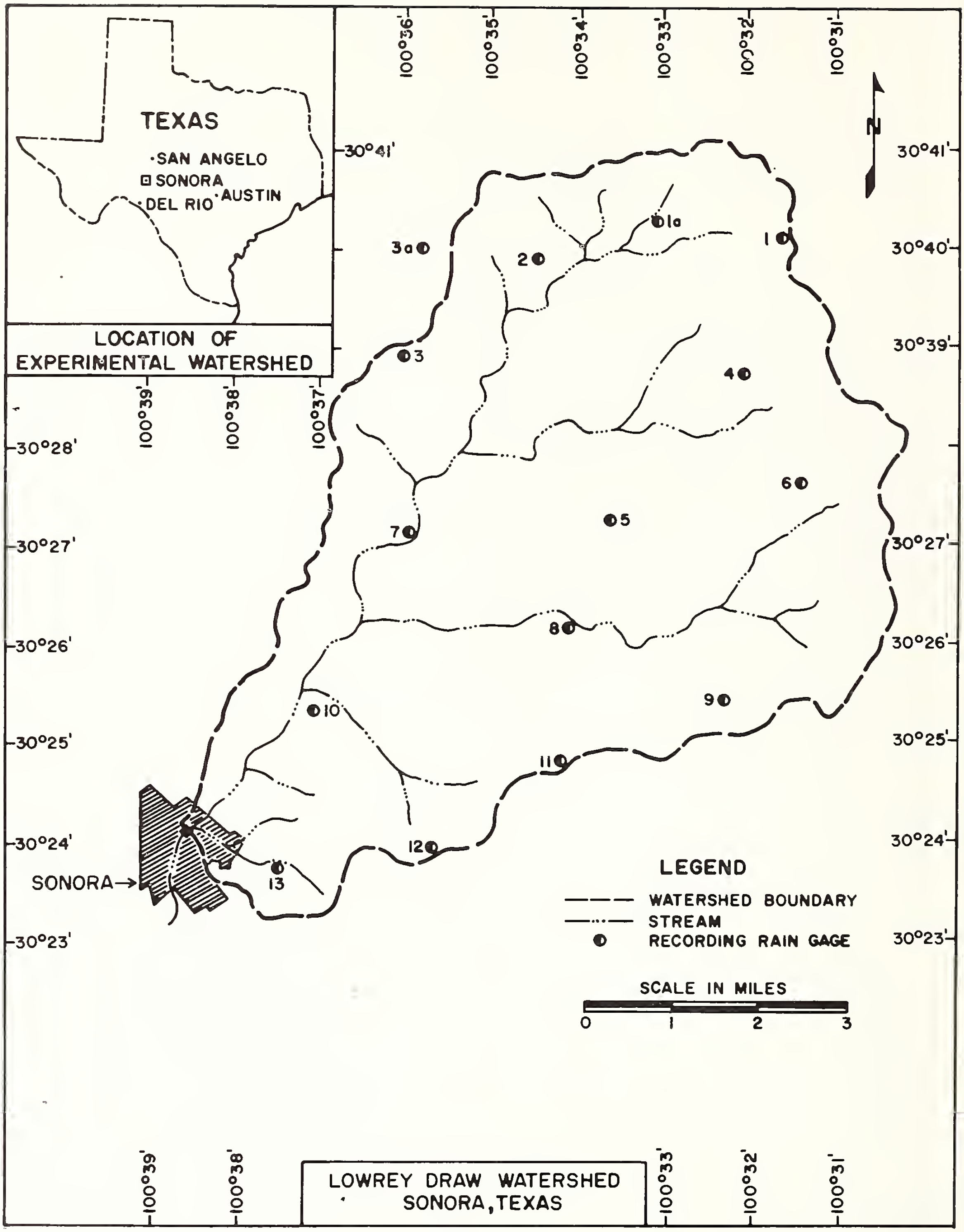

Figure 1.—Rain gage network at Lowrey Draw Watershed, Sonora (Sutton County) Tex.

Table 1.—Rain gage network description for Lowrey Draw Watershed, Sonora, Tex.

Rain gage[1] No.	Period of record		Elevation above mean sea level
	From	To	
			Feet
1	6-14-61	Present	2,390
1a	11-20-61	. . do . .	2,344
2	6-07-61	. . do . .	2,335
3	6-07-61	4-29-65	2,325
3a	4-29-65	Present	2,327
4	6-15-61	. . do . .	2,362
5	6-15-61	. . do . .	2,358
6	6-08-61	. . do . .	2,365
7	6-08-61	. . do . .	2,205
8	6-08-61	. . do . .	2,305
9	6-15-61	. . do . .	2,352
10	6-08-61	. . do . .	2,170
11	6-15-61	. . do . .	2,340
12	6-06-61	. . do . .	2,318
13	6-06-61	. . do . .	2,195

[1] All gages are weighing-recording type with 12-hour time scale.

Table 2.—Maximum, minimum, and average monthly precipitation at rain gage 9, Sonora, Tex., 1962-68

Month	Maximum	Minimum	Average
	Inches	*Inches*	*Inches*
Jan.	2.32	0.04	0.99
Feb.	2.40	.42	1.20
Mar.	1.81	.13	.78
Apr.	6.75	1.15	3.03
May	7.13	.58	3.56
June	3.46	.50	1.67
July	3.65	.31	2.08
Aug.	2.64	.21	1.27
Sept.	10.65	.53	4.20
Oct.	1.76	.36	1.25
Nov.	3.28	.08	1.47
Dec.	1.29	T	.62
Yearly totals	28.49	15.79	22.12

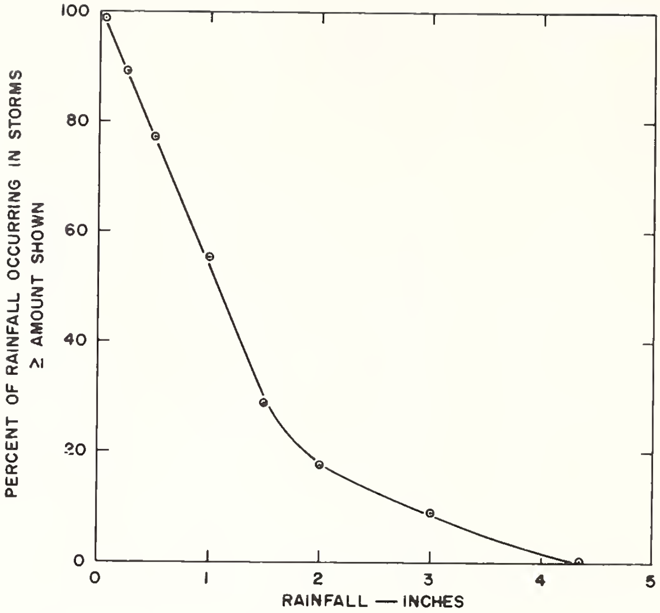

Figure 2.—Rainfall distribution by size of storm at rain gage 9, Lowrey Draw Watershed, Sonora, Tex., 1961-68.

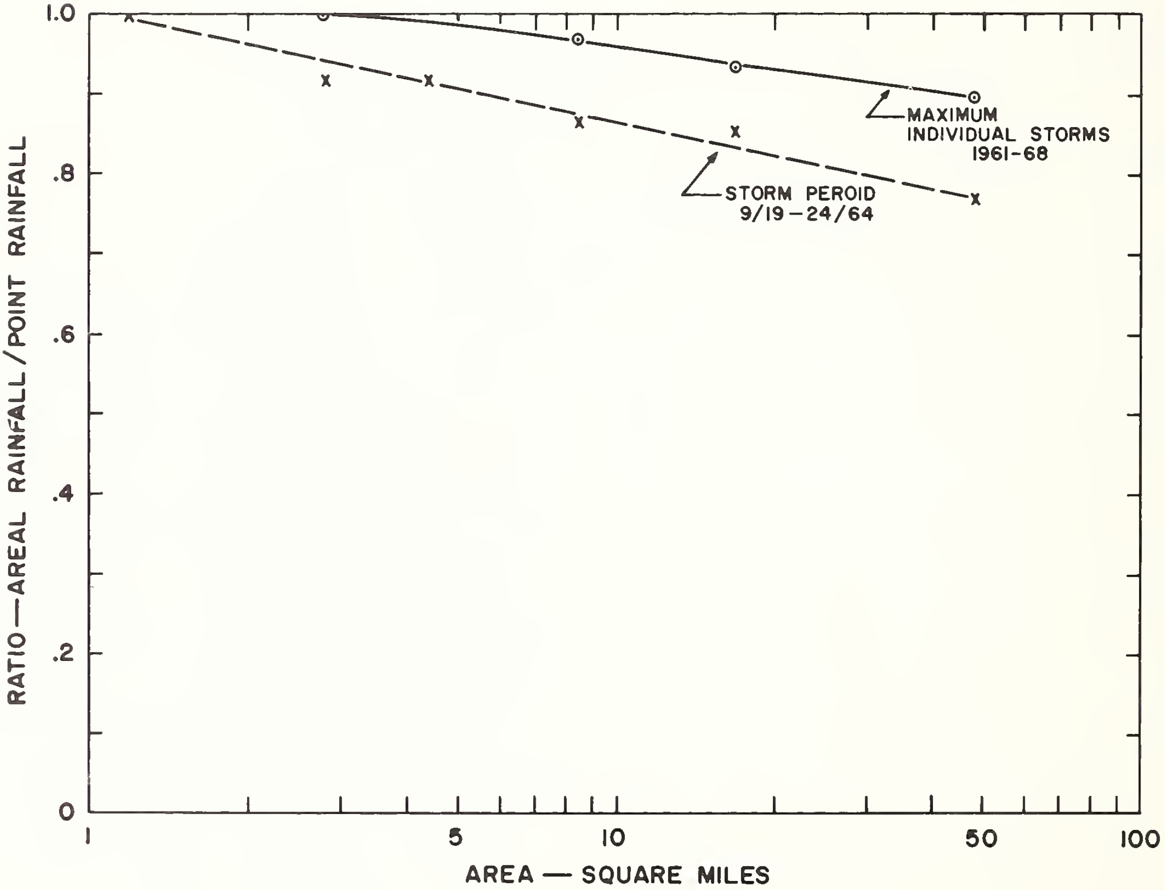

Figure 3.—Relationship of ratio of areal to point rainfall and size of area, Sonora, Tex., 1961-68.

approximately the same at all gages. The second criterion was not met because the annual events were not entirely independent at all gages. However, several storms were represented each year. For 111 station-years of record, the five largest 60-minute amounts occurred in different years and at different stations. The 10 largest amounts occurred in 7 different years and eight different storms. Since the largest events were relatively independent, a station-year analysis may be justified. A frequency analysis was made by the Gumbel procedure for fitting to the Fisher-Tippett Type I distribution. The 100-year 60-minute rainfall was estimated to be 3.76 inches as compared with the U.S. Weather Bureau value of 3.48 inches. A similar analysis made with 55 station-years of data (1961-64)[3] resulted in an estimate of 3.64 inches. Observational data have equaled or exceeded the U.S. Weather Bureau 100-year value of three different rain gages in 3 separate years. The analysis shows that short-term network records can be utilized in frequency analysis in semiarid areas.

Probability studies of clock-hour point and areal rainfall were made by Heaton.[4] A significant difference was found between conditional probability distributions of point and areal rainfall. An important difference was that point distributions gave a high probability of a dry hour following a wet hour as opposed to relatively lower probabilities for areal rainfall. Storm travel over the 48-square-mile area is a major factor in the relative difference. A first-order Markov model gave satisfactory results in predicting hourly rainfall states within 10 rainfall classes based on hourly accounts. Rainfall states for times greater than 1 hour required higher order Markov models. Heaton recommended a Markov process for synthesizing areal precipitation as an input for streamflow forecasting.

SUMMARY

Rainfall in this semiarid area is generally highly variable. However, maximum ratios of areal to point rainfall are relatively high for individual storms associated with frontal movement. The station-year method of frequency analysis has been proven valid for this meteorologically homogeneous, semiarid area without orographic influence. A Markov process has been used to estimate rainfall states by storm class for hourly amounts.

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[3] Part-year record for 1961, but maximum at U.S. Weather Bureau cooperative observer gage occurred after the Lowrey Draw network was established.

[4] Heaton, L. R. An investigation of the variability of rainfall statistics over a small area with varying rain-gage density. 48 pp. 1948. [Unpublished master's thesis. Copy on file at Texas A & M University, College Station.]

CHAPTER 16.--DANVILLE, VERMONT

R. L. Hendrick[1]

WATERSHED LOCATION AND OBJECTIVES

In 1957, the Agricultural Research Service selected the 43-square-mile Sleepers River Basin in northeastern Vermont as a suitable site for the establishment of a research watershed. The research is designed to develop understanding and to impove prediction of the hydrologic and water-related environmental processes in the water source regions of New England.

The Sleepers River watershed was selected as a drainage area typical of the formerly glaciated rural New England highlands in terms of topography, land use, vegetation patterns, geology, and climate. As a small source area for the upper Connecticut River, the Sleepers River is a part of the largest, most developed, and increasingly the most critical river water system in New England, thereby providing direct resource and conservation applications for research studies. Figure 1 shows the location of the Sleepers River watershed within the Connecticut River Basin. Figure 2 is a map of the topography, drainage network, streamflow measurement sites, and rain gage locations.

TOPOGRAPHY AND CLIMATE

The watershed is characteristic of cold climate, upland, rural New England with small dairy farms, small villages, and forested hills. Elevations range from 660 to 2,590 feet, with a general slope and drainage from west-northwest toward east-southeast. Except along the highest ridge on the extreme western boundary, the landscape is rather gentle and rolling. About two-thirds of the watershed is forested with a mixture of northern hardwoods and spruce-fir; the rest is mostly farm hayland.

The precipitation climate was summarized in considerable detail by Engman and Hershfield (3). The spatial variation of annual precipitation from 30 to 45 inches is clearly related to elevation; this effect of greater precipitation at higher elevations is most pronounced in winter. Precipitation is ample during all seasons but, unlike

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[1] Meteorologist, U.S. Dept. Agr., Agr. Res. Serv., Soil and Water Conserv. Res. Div., Danville, Vt. 05828.

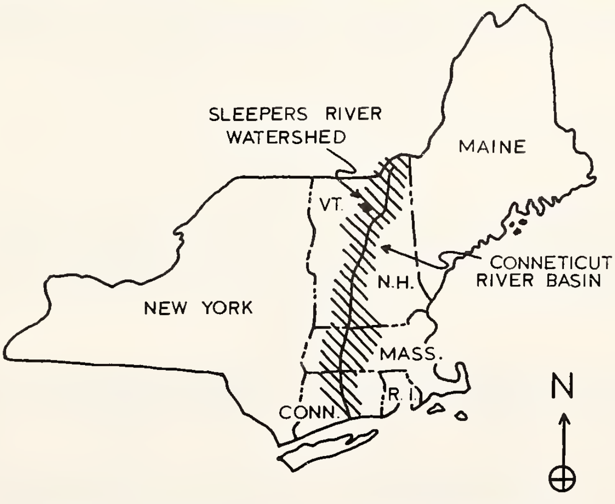

Figure 1.--Sleepers River watershed in the Connecticut River Basin.

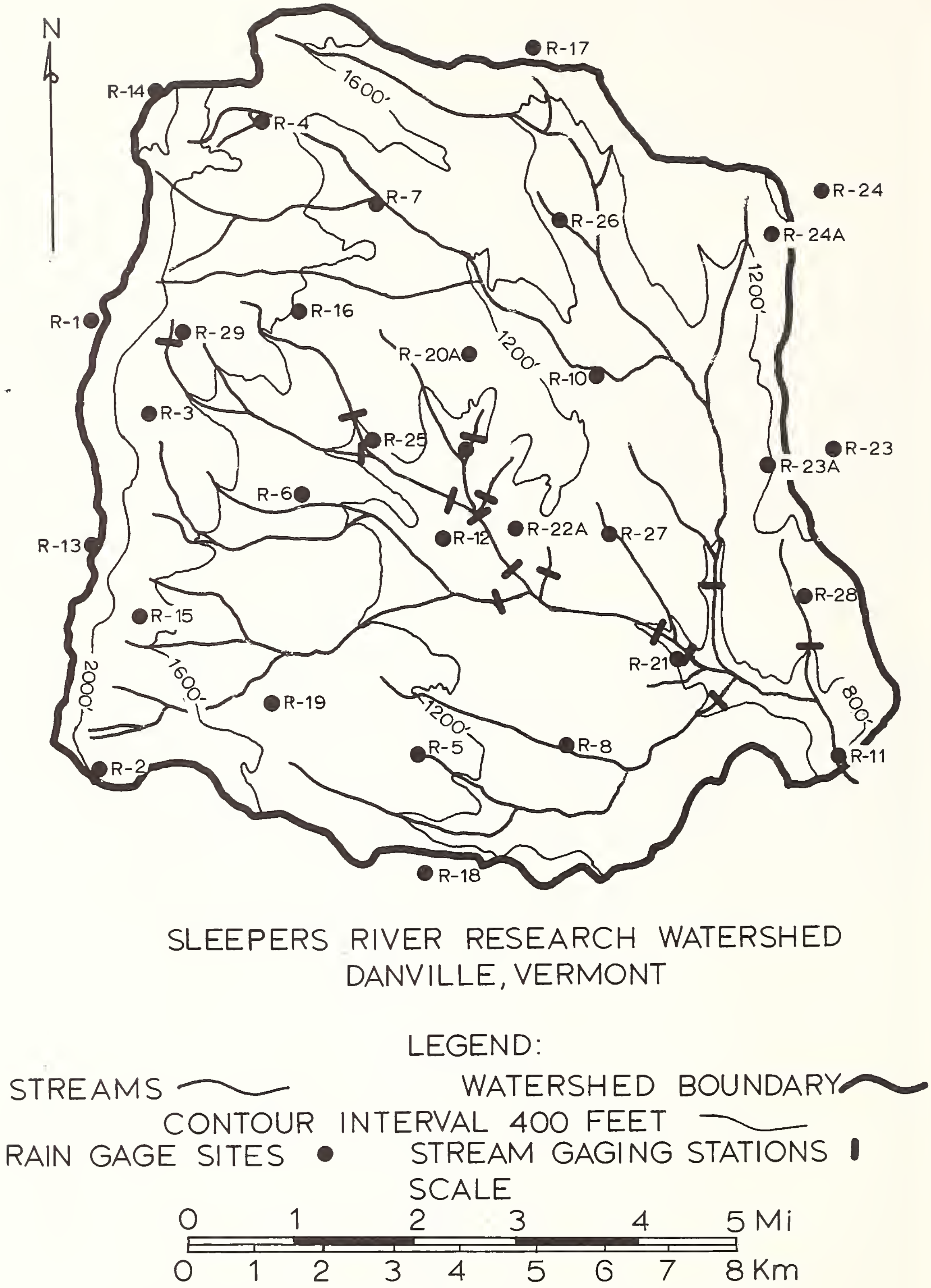

Figure 2.–Rain gage and stream gage networks, Sleepers River watershed, Danville, Vt.

the regions immediately to the south in southern New England, there is a distinct seasonal pattern with a winter minimum and a summer maximum. (Average precipitation at St. Johnsbury is 2.57 inches in January and 3.47 inches in July.)

The temperature pattern strongly influences the precipitation of the region. The winter climate is dominated by cold continental air, which flows over the region from the northern United States and Canada. Mean January temperature is 14° F., below zero temperatures are common. Frost first occurs in early September, the first snows usually arrive in early November, and a continuous snow cover is common from early December until early April. During this period, at least one-fourth of the annual precipitation may be expected to fall as snow, which builds up to between 15 and 60 inches, with 5 to 20 inches of water content, by late March. This buildup sets the stage for what is ordinarily the most significant hydrologic process of the year, the spring snowmelt runoff.

More than one-half of the annual runoff usually occurs during April and May. The variations in elevation, slope-aspect, and forest cover tend to spread this melt over 3 to 8 weeks, and spring floods are not as common as one might expect from the water content of the snow. Because of the spatial variations in snowmelt and the resulting time staggering of the snowmelt runoff, serious spring flooding requires a rather special and uncommon combination of meteorological factors and snow conditions. Spring flooding is most serious when substantial rains fall during weather conditions that produce concurrent rapid melting in all watershed environments. These weather conditions are high temperatures, high humidity, and moderate to strong winds. A classic combination of these rainfall and melt factors occurred in March 1936, producing record flooding throughout the Connecticut River Basin. During the 12 years of Sleepers River watershed operations, no important flooding has taken place. Spring runoff in 1969 was about normal in spite of record high water content of the snowpack.

Spring rain and snowmelt are not the only flood-producing factors. The record flood in the Vermont uplands occurred in November 1927, and the record rainfall and runoff during the 12 years of Sleepers River measurements occurred in October 1962. These late summer and autumn rainfalls are associated with tropical storms that occasionally find their way into northern New England and produce several inches of steady rain, usually over a 1- to 3-day period. These tropical rains can cause rapid rises in streams even when low flows and dry soils exist at the beginning of the storm.

Other flooding possibilities include local flash flooding on small streams from short but very heavy summer thunderstorms (6). Winter thaws accompanied by heavy rains could produce some floodings, particularly if ground frost is widespread, but this has not been observed during the 12 years of watershed observations.

THE RESEARCH PROGRAM

Research programs directed toward improved understanding of water-related processes in the upper New England water source regions have stressed the interactions between atmospheric environments of rainfall, snowfall, temperature, humidity, wind, and radiation, and the land environments of topography, vegetation cover, land use, soils, and geology. The resulting hydrologic processes of infiltration, runoff, evapotranspiration, snowmelt, channeling, sedimentation, nutrient cycling, and stream pollution are of particular interest.

THE PRECIPITATION OBSERVATION SYSTEM

Approximately one-fourth of the average annual precipitation of 30 to 45 inches falls as snow. The water input is not adequately defined by the undifferentiated rain gage catch, because so much precipitation input is delayed until snowmelt. Precipitation input therefore requires one measurement system for rainfall and another for snowmelt.

THE RAIN GAGE NETWORK

The original network of 15 gages installed in September 1958 was designed to achieve the following measurement objectives:

1. Approximately equal area representation over the entire 43 square miles of watershed.
2. Representation of the entire elevation range.

3. Location of a rain gage in each stream-gaged subwatershed.
4. Establishment of a baseline gage, centrally located at the average elevation (R-12).

Rain gages were added as new subwatersheds were gaged and as research projects required either a denser coverage or point measurements in particular environments. The maximum rain gage coverage of 32 gages was reached in 1964. A re-analysis of rain gage network requirements in November 1969 led to a slight reduction to 27 permanent gages.

The number and location of rain gage sites that have been used during the 12-year watershed history are shown in figure 2. Table 1 lists each gage number, its period of chart rotation, elevation, and length of record.

Table 1.—Precipitation gage data, Sleepers River Research Watershed, Danville, Vt.

Gage No.	Checked rotation	Elevation above mean sea level	Record began
	Hours	*Feet*	*Date*
R-1	24	2,200	9/10/58
R-2	24	1,900	9/22/58
R-3	24	1,810	11/28/60
R-4	24	1,810	12/ 9/60
R-5	24	1,320	12/ 7/60
R-6	24	1,350	1/ 1/61
R-7	96	1,380	9/10/58
R-8	24	960	12/ 7/60
R-10	24	960	9/10/58
R-11	24	660	9/10/58
R-12	24	1,150	9/ 3/58
R-13	96	2,210	9/21/61
R-14	96	2,590	3/ 9/62
R-15	24	1,680	9/19/62
R-16	96	1,580	9/12/58
R-17	96	1,300	9/10/58
R-18	96	1,350	9/10/58
R-19	24	1,440	9/10/58
R-20	24	1,080	12/ 7/60
R-20a	24	1,340	[1] 12/ 9/60
R-21	24	740	5/19/60
R-22	24	950	12/ 7/60
R-22a	24	1,150	[1] 9/10/58
R-23	24	1,240	[1] 9/10/58
R-23a	24	1,240	11/ 2/61
R-24	24	1,250	[1] 9/10/58
R-24a	24	1,250	11/ 2/60
R-25	24	1,150	12/20/66
R-26	96	1,140	2/12/64
R-27	96	1,040	2/12/64
R-28	96	960	2/12/64
R-29	96	1,720	[1] 6/10/64

[1] Terminated in 1969.

All network rain gages are the standard U.S. Weather Bureau weighing-recording gage. Each gage, except R-14, is mounted on a permanent concrete base with the orifice 40 inches above the ground surface. The gage is raised to an orifice height of 72 inches above the ground for winter operation in order to keep well above the snow surface. Station R-14, located in a remote wooded site at the highest watershed elevation of 2,590 feet, is permanently mounted on a tower 10 feet above the ground and is serviced by climbing a ladder to the small mounting platform.

Funnels are removed from the orifices to prevent snow bridging during winter, and an antifreeze solution in the receptacle melts the snow as it falls. All gages are calibrated every 6 months.

Alter shields are installed on three gages—R-1, R-12, and R-22a—which are in exposed, windy locations. In October 1969, a second gage with alter shield was installed at R-19, a windy site where the unshielded gage appears to have less precipitation than would be expected at its elevation.

Each site is enclosed in a fenced, small grass plot, which is kept mowed. These plots are either in open farm fields or in a clearing where no trees are closer than 15 feet and, except for a few unavoidable situations, the elevation angle to any treetop is less than 30° above the horizon.

At the baseline rain gage station R-12, a standard 8-inch gage is measured each day for backup and comparative precipitation information.

THE SNOW COURSE NETWORK

Because the precipitation gage does not discriminate between liquid and frozen precipitation, and because most December through March precipitation is in the form of snow, it is extremely important that careful account of snow accumulation and melt be kept if the hydrology of the watershed is to be understood.

In January 1960, 12 snow courses were laid out and put into operation. Other snow courses were added until 21 courses were in operation by 1965. This number was reduced to 13 regular courses by the 1969-70 winter, although a new experimental course was added.

The measurement objectives of the snow course network are as follows:

1. To record spatial distributions of snow depth, water content, and density throughout the winter and spring seasons.
2. To determine time and space distributions of snowmelt.
3. To acquire adquate data to investigate environmental effects on snow accumulation, redistribution, metamorphosis, and melt.

The procedures for snow course observation are standard, Once every week, five samples are taken along each course with an Adirondack snow sampler. These are weighed and averaged to obtain an average depth, density, and water content at each course. During periods of rapid spring melt, samples may be taken twice weekly. Figure 3 is a map of the snow course network, and table 2 shows the elevation and length of record at each site. Each snow course is located in an open area or in a forested clearing to avoid drifting or unusual effects on the snowfall. Two courses, S-29 and S-14, are exceptions. These are located in hardwood forest stands. All other courses are exposed to nearly full daytime sunshine and are on nearly level land to preclude important slope-aspect effects on melting. All snow course areas are fenced in to prevent human or animal disturbance of the snow pack. Most of those courses that were discontinued were found to be subject to drifting, ground water seeps, or other disturbances.

Table 2.–Snow course data, Sleepers River Research Watershed, Danville, Vt.

Course No.	Elevation above mean sea level	Record began
Feet	*Feet*	*Date*
S-1	2,200	1/ 4/60
S-2	1,900	1/12/60
S-3	1,810	1/ 4/60
S-3a	2,150	12/ /69
S-4	1,810	1/ 5/61
S-5	1,320	12/13/60
S-6	1,350	[1] 1/ 4/60
S-7	1,380	1/ 5/60
S-8	960	1/12/60
S-9	960	1/ 4/60
S-10	960	1/ 5/60
S-11	660	1/ 4/60
S-12	1,150	[1] 1/ 5/60
S-13	2,210	3/ 6/61
S-14	2,590	1/12/60
S-15	1,680	[1] 12/21/61
S-16	1,580	12/18/61
S-19	1,440	12/ /69
S-20a	1,340	[1] 12/28/61
S-22	950	[1] 12/28/61
S-22a	1,150	[1] 1/ 4/62
S-25	1,150	1/ 4/62
S-29	1,720	[1] 4/19/65

[1] Terminated in 1969.

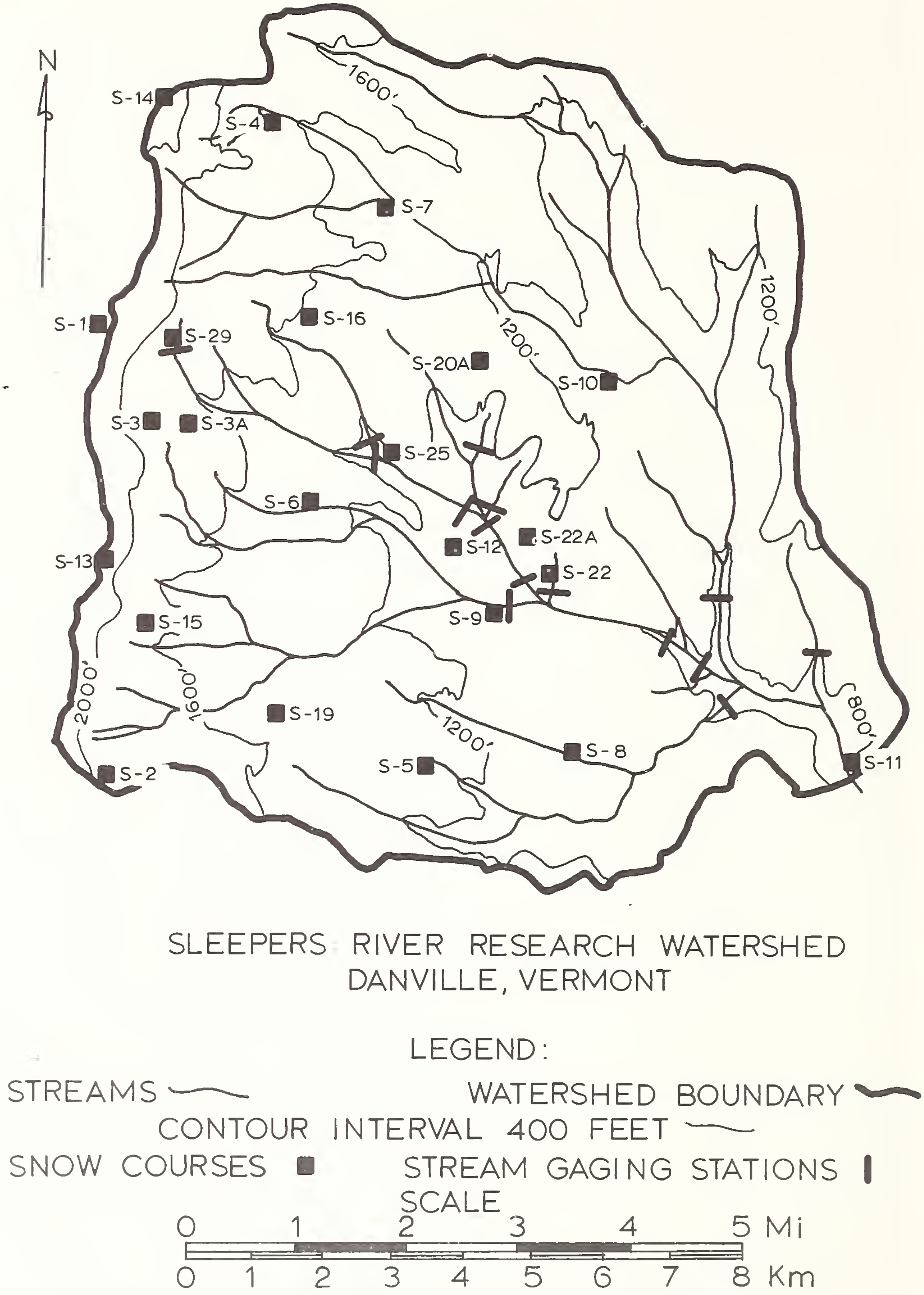

Figure 3.–Snow course network, Sleepers River Research Watershed, Danville, Vt.

An experimental snow course, S-3a, was established in December 1969, under a dense spruce-fir canopy. Special spot measurements taken during snowmelt seasons in 1967, 1968, and 1969 suggest that the woodland distribution has very important effects in staggering snowmelt during the spring season. The new S-3a site will provide comparative accumulation and melt data for woodlands on a regular basis.

THE PRECIPITATION DATA PROCESSING SYSTEM

Precipitation gage data and snow course data are processed for card and tape storage and data output listings (table 3). The 24-hour precipitation recording charts are analyzed on a chart reader for each change in precipitation rate (breakpoint) during every storm period. This information is punched on cards and computer processed to generate output listings. The 24-hour gage output information includes gage number, date, time, time interval between breakpoint, acccumulation for time interval, intensity for time interval, storm accumulation, monthly accumulation, and maximum storm intensities for all storms of 0.25 inch or more for periods of 2, 5, 10, 15, 20, and 30 minutes; 1 hour; and 2, 4, 6, 12, and 24 hours. Listings of the 96-hour gages are simply monthly summaries of daily precipitation.

WATERSHED STUDIES AND SIGNIFICANT FINDINGS

The entire spectrum of observational and research work at the Sleepers River Research Watershed was recently summarized by Johnson (7).

In addition to the analysis of precipitation climatology by Engman and Hershfield (3), a number of watershed studies have either directly or indirectly involved the regular network or special precipitation and snowmelt measurements. These studies, with their objectives and most significant findings, are briefly summarized.

1. An analysis of the spatial variations of daily precipitation as represented by correlation fields about a central gage was made by Hendrick and Comer (4). This study showed a strong azimuth bias to the correlation field, suggesting that the direction of moisture advection aloft during storms is the predominating process affecting the areal association between gage catches. If network design is to reflect spatial relationships in daily rainfall, the spacing of gages in the mean direction of moisture flux (west-southwest to east-northeast) could be about twice that in the north-northwest to south-southeast direction, and a winter network need be only about one-half as dense as a summer network.
2. As part of an intensive study of contributions to streamflow during snowmelt, Dunne[2] was able to show a very quick response in surface runoff to short wave solar radiation on the melting snow surface. He also showed the significance of the expanding partial area contributing to runoff during rapid snowmelt.
3. A more general study of the contribution of snowmelt to runoff and the effect of soil type on subwatershed runoff was recently completed by Johnson.[3] The ratio between storm runoff and precipitation was highly dependent on soil type. He found a very strong relationship between the total water equivalent of the snowpack at the beginning of spring melt and the total annual yield of the subwatersheds, thus verifying the profound importance of snow hydrology to the water regimen of the region.
4. A cooperative project with ESSA to investigate the physical processes and energy budget of melting snow has been in progress for 3 years (8). The objective is to improve snowmelt models for melt-runoff predictions. Special instrumentation to measure the profile of water content in the snowpack was developed for this project by Howe and Houghton (5). This project is aimed at measuring and understanding energy and mass exchange in a snowpack during melt as determined from detailed measurements at a point. The results will then be applied to the melting of the snowpack over the entire watershed.

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[2] Dunne, Thomas. Runoff contributions to streamflow from permeable hill-slopes in Danville, Vt. 1968. [Thesis presented to Johns Hopkins Univ., Baltimore, Md., in partial fulfillment of requirements for degree of Doctor of Philosophy.

[3] Johnson, Martin L. Runoff from eight watersheds in northeastern Vermont. 1969. [Thesis presented to Johns Hopkins University, Baltimore, Md., in partial fulfillment of requirements for degree of Doctor of Philosophy.]

Table 3.—Input and output status of precipitation gages and snow courses as of February 1, 1970, Sleepers River Research Watershed, Danville, Vt.

Site No.	Input status	Output status
	Date	*Date*
R-1	9/10/58 - 12/31/69	9/10/58 - 12/31/67
R-2	9/22/58 - 12/31/69	9/22/58 - 12/31/67
R-3	11/28/60 - 12/31/69	11/28/60 - 12/31/67
R-4	12/ 9/60 - 12/31/69	9/20/61 - 12/31/67
R-5	12/ 7/60 - 12/31/69	12/ 7/60 - 12/31/67
R-6	1/ 6/61 - 12/31/69	1/ 6/61 - 12/31/67
R-7	9/10/58 - 12/31/64	9/10/58 - 12/31/64
R-8	12/ 7/60 - 12/31/69	12/ 7/60 - 12/31/67
R-10	9/10/58 - 12/31/69	9/10/58 - 12/31/67
R-11	9/10/58 - 12/31/69	9/10/58 - 12/31/67
R-12	9/ 3/58 - 12/31/69	12/31/64 - 12/31/67
R-13	(1)	(2)
R-14	(1)	(2)
R-15	9/19/58 - 12/31/69	9/19/58 - 12/31/67
R-16	9/12/58 - 12/31/63	12/31/60 - 12/31/63
R-17	(1)	(2)
R-18	9/10/58 - 12/31/63	9/10/58 - 12/31/63
R-19	9/10/58 - 12/31/69	12/31/62 - 12/31/67
R-20	12/ 7/60 - 12/31/69	12/ 7/60 - 12/31/67
R-20a	12/ 9/60 - 10/ 1/69	12/ 9/60 - 12/31/67
R-21	5/19/60 - 12/31/69	5/19/60 - 12/31/67
R-22	12/ 7/60 - 12/31/69	12/ 7/60 - 12/31/67
R-22a	9/10/58 - 12/31/69	9/10/58 - 12/31/67
R-23	(1)	(2)
R-23a	11/ 2/61 - 12/31/69	11/ 2/61 - 12/31/67
R-24	9/10/58 - 12/31/69	9/10/58 - 12/31/69
R-24a	11/ 2/60 - 12/31/69	11/ 2/60 - 12/31/67
R-25	12/20/66 - 12/31/69	12/20/66 - 12/31/67
R-26	(1)	(2)
R-27	(1)	(2)
R-28	(1)	(2)
R-29	(1)	(2)
S-1	1/ 4/60 - 5/31/66	12/ 1/62 - 5/31/64
S-2	1/12/60 - 5/31/66	12/ 1/62 - 5/31/64
S-3	1/ 4/60 - 5/31/66	12/ 1/62 - 5/31/64
S-3a	(3)	
S-4	1/ 5/61 - 5/31/66	12/ 1/62 - 5/31/64
S-5	12/13/60 - 5/31/66	12/ 1/62 - 5/31/64
S-6	1/ 4/60 - 5/31/66	12/ 1/62 - 5/31/64
S-7	1/ 5/60 - 5/31/66	12/ 1/62 - 5/31/64
S-8	1/12/60 - 5/31/66	12/ 1/62 - 5/31/64
S-9	1/ 4/60 - 5/31/66	12/ 1/62 - 5/31/64
S-10	1/ 5/60 - 5/31/66	12/ 1/62 - 5/31/64
S-11	1/ 4/60 - 5/31/66	12/ 1/62 - 5/31/64
S-12	1/ 5/60 - 5/31/66	12/ 1/62 - 5/31/64
S-13	3/ 6/61 - 5/31/66	12/ 1/62 - 5/31/64
S-14	1/12/60 - 5/31/66	12/ 1/62 - 5/31/64
S-15	12/21/61 - 5/31/66	12/ 1/62 - 5/31/64
S-16	12/18/61 - 5/31/66	12/ 1/62 - 5/31/64
S-19	(3)	
S-20a	12/28/61 - 5/31/66	12/ 1/62 - 5/31/64
S-22	12/28/61 - 5/31/66	12/ 1/62 - 5/31/64
S-22a	1/ 4/62 - 5/31/66	12/ 1/62 - 5/31/64
S-25	1/ 4/62 - 5/31/66	12/ 1/62 - 5/31/64
S-29	4/19/65 - 5/31/66	12/ 1/62 - 5/31/64

[1] No inputs. [2] No outputs. [3] Initiated Dec. 1969.

5. The rain gage network data and runoff data have been used to estimate evapotranspiration over the watershed (1). This simple balance approach appears valid because the geology of the watershed is not favorable for significant losses to deep seepage or underground transport across watershed boundaries. Annual evapotranspiration estimates by this method were about 56 percent of pan evaporation.
6. Comer and Zimmermann (2) studies annual precipitation and low flows in two basins and were able to show the important role of soil types in determining the precipitation-runoff relationships.
7. Kunkle (9) has also used rainfall data, in addition to artificial sprinkling, to derive new relationships between bacterial indicators and farm surface runoff. He found that natural summer storms of 1 to 2 inches produced ranges of total coliform concentrations from 1,000 to 320,000 per ml., these concentrations rising and falling with the stream level. Substantially less variation was found for fecal coliforms. His experiments raise questions about the validity of using total coliform count as a stream pollution index.

SUMMARY

Sleepers River watershed investigations include hydrology, meteorology, biology, geology, geomorphology, and other special disciplines that relate to the water resources in the upper New England region. The rain gage and snow course networks have been established and are maintained and modified to support a varied environmental studies program. The networks are designed to adequately measure the total water input in this region where snowfall and melt is a very significant part of the annual hydrology.

The research program draws heavily on these water-input networks in determining atmospheric and environmental interactions affecting many hydrologic and water quality processes.

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